Water resources, food security and virtual water 'trade' in the Middle East and North African region

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ABSTRACT

The main purpose of this study is to analyse the relationship between water, food security and trade in the MENA region. Water and food security are inextricably linked because of the poor water endowments of the region and the high volumes of water needed to produce food commodities, which account for 90% of the water needed by societies. The concepts of virtual water and water footprints are deployed critically in the study. Estimates of water requirements to produce a targeted diet are related to total water resources locally available for food production. The purpose is to assess the capacity of MENA economies to meet their food needs. This element of the study is original in that it accounts not only for *blue* (surface and ground-) but also *green* (soil) water resources. The MENA is not rich in green water resources but they do provide a substantial proportion of the water used in food production.

The study also investigates the extent to which the region's economies have relied on virtual water 'imports' to meet their food needs over the past two and a half decades. It shows that the region's economies have all become net virtual water 'importers' and are dependent on global natural resources. Food, especially crops, account for the largest share (95%) of virtual water 'imports'. The study shows that virtual water 'imports' mainly originate from *outside* the region, whereas 'exports' are regionalised. The study shows that the largest share of 'imports' is *green* and originates from Brazil, the USA and Russia. Finally, the study argues that water security is less dependent on water endowments than it is on the socio-economic strength and diversification of the MENA economies. These capacities determine the level and effectiveness of water use of water and, most importantly, the capacity to 'import' virtual water.

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EU European Union

FAO Food and Agriculture Organisation of the United Nations

GCC Gulf Cooperation Council (Saudi Arabia, UAE, Kuwait, Bahrain, Qatar, Oman)

GDP Gross Domestic Product

GNI Gross National Income

GNP Gross National Product

HDI Human Development Index

IFPRI International Food Policy Research Institute

IMF International Monetary Fund

IPCC Intergovernmental Panel on Climate Change

MCM Million cubic meters

N/A Not available

OPT Occupied Palestinian Territories

UN United Nations

UNDESA United Nations Department of Economic and Social Affairs

UNDP United Nations Development Programme

UNPD United Nations Population Division

USA United States of America

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1. Introduction: The Middle East and North Africa water question

1.1 Introduction

The main purpose of this study is to analyse the relationship between water, food security and trade in the arid and semi-arid Middle East and North Africa (MENA). The region is widely acknowledged as being amongst the most water scarce in the world and currently faces the difficult combination of a number of socio-economic and environmental challenges. Drivers of the region's demand for water are mainly the increasing demand for food associated with population growth, the advancement of the region's economies coupled with rapid urbanisation, and the associated changes in living standards and diets. In this context, the study aims to increase understanding of the political economy processes that have determined, and will determine in the future, water and food security in the region.

The water insecurity of the MENA is not only rooted in its poor resource endowments, but also in the very limited capacities of the region's agricultural sectors and governments to adapt and make the most of local water resources endowments. The overwhelming majority (over 70%) of the water withdrawn from surface and groundwater bodies is allocated to agriculture (Molden 2007). These blue water resources are over-abstracted and their ecosystem services have been very negatively impacted. The extent to which soil – or green – water underpins local food production has neither been sufficiently recognised by policy makers nor taken into account in water resource planning (Chatterton and Chatterton 1996; Allan 2001). The socio-economic 'adaptiveness' of the region's political economies will be argued to be the main explanatory factor of *how* available water resources are used.

As a consequence of the very high volumes of water required to grow crops, water and food security are closely linked. Almost any society can meet its municipal and industrial water requirements but the same statement does not hold true for food production. *Food-water* is the water needed to produce food and accounts for 90% of the water needed by an individual or a society, as opposed to *non-food water*, that is the water used by households and industry (Allan 2013a, 2013b). The concept of 'food-water' is used throughout the study in order to capture the link between water and food security, and also for drawing attention on the political economy processes that underpin water and food security in the MENA – as well as in other water-deficit countries in the world. The concepts of *virtual water* and *water footprints* are also deployed critically.

The water demands of the MENA economies have exceeded the capacity of their own resource base to underpin food self-sufficiency and they entered water stress by the second half of the twentieth century. The region is a net importer of food commodities – grains in particular. The import of food can be considered as an import of the water 'embedded' – as a factor of production – in the traded commodities (Allan 2001). Current and future tensions in the region will arise from how the political economies of the region will manage the water-deficit and secure the food-water needs of their populations.

The study will situate the water and food-related challenges faced by the region in the wider context of international trade, showing that economic systems have enabled the MENA countries to access water in the global hydrological systems via trade and effectively to alleviate the local water resource deficit. The study will show that the region's water and food security currently depend more on water from *outside* the region, 'embedded' in food imports and accessed through trade, than on local water endowments. The study will show that market-mediated 'import' of water in virtual form has effectively and invisibly provided the region's water-deficit economies with its *food-water* requirements over the past two and a half decades.

The structure of this chapter is as follows. The next section outlines the thematic scope of the study. What follows is a preliminary review of the literature and the relevant concepts informing the study, and a description of the geographical and historical scope of the research. The last two sections present the research questions and the overall structure of the study.

1.2 The research problem

Water is the life-giving resource *par excellence*. Water plays a central role in determining the genesis, development and lifespan of all living organisms – vegetal, animal and human. As the "bloodstream of the biosphere" (Ripl 2003: 1921), water has shaped, and will continue to shape, the face of our planet.

Throughout history, water resources have impacted not only physical geography, but also human geography. The availability and quality of water have fundamentally determined the establishment of human settlements, and has very strongly influenced the ability of societies to thrive in their environments. Water geographies are reflected in the boundaries of any human settlement, from tribes, to cities and states. Water resource availability has also strongly influenced the history and patterns of migrations, often supporting coping mechanism against extreme events, such as floods or droughts.

The reason why societies thrive in water rich environments is related not only to the role that water plays in underpinning daily domestic activities – such as bathing, cooking and cleaning – but also, and more importantly, to its vital contribution to food production as a primary input for agriculture – whether it be irrigated or rainfed. Historically, agricultural production first served the purposes of the farm family's food self-sufficiency and then developed into barter and trade of goods. As human settlements grew into cities, generally nearby river flows in order to enable transportation of goods, the demand for food grew accordingly and, thereby, the necessity to control water systems through the development of water resource infrastructures.

The way societies adapted to the rules of nature has determined, thorough time, the sustainability of societal development. Where the appropriation and exploitation of water resources have been pursued at an unsustainable pace and regardless of local water budgets, human intervention has impaired the natural resource base and caused damage to local ecosystems. In these contexts, the basic functions of freshwater systems, for both people and nature, are increasingly difficult to sustain.

In the Middle East and North African region, the driest region in the world, addressing the question of the sustainability of water resource use is more urgent than anywhere else. The region's economies endure increasingly arid and semi-arid circumstances and have rising populations. Irrigated agriculture is by far the biggest user of freshwater despite it being associated with the lowest economic returns of any other possible productive water use. It provides the main source of livelihood for rural societies in the non-oil economies of the region and it is also a very attractive option for local farmers, mainly because of the prevalence of high temperatures that sustain crop growth. The traditional prioritisation of irrigated farming, both in water allocation and water policy discourse, has also been reinforced by the deeply entrenched notion that irrigation is "worthy, essential and even holy" (Allan 2007: 64).

The unsustainable rates of water withdrawal for agriculture has, over time, brought about very difficult challenges for those responsible for using and allocating water in the MENA region. Allan (2001) observed that since the 1970s the region's economies have been relying on imports to meet their food requirements, as local water supplies ceased to meet water demands. Thereafter, the availability of water has become a limiting factor or even a constraint on some elements of economic development that require high volumes of water.

The water deficit in the MENA region is also likely to get worse in future. Per capita water availability in the region is expected to fall by half by 2050 at the expense of the already stressed local resource base (World Bank 2007). The region is currently facing unprecedented challenges resulting from the combination of rapid demographic growth and urbanisation, the advancement of the region's economies, the increase in the consumption of animal-based products, and the prospects of climate warming. All these factors will drive a dramatic increase in water demands and thus call for the need to re-think the region's water resource management and policy in a more sustainable way.

1.3 Preliminary considerations of literature review and aims of the study

1.3.1 The concept of virtual water and its relevance for the study

A major breakthrough in the analysis of the MENA region's water question has been the conceptualisation of *virtual water* by Allan in the early 1990s. Virtual water is the water 'embedded' in food and other commodities (Allan 1993). The concept is critically deployed in the study as it effectively captures the relationship between water resource scarcity, food security and agricultural trade in the MENA region. The water virtually 'embodied' in food commodities accounts for the largest share of the water needed by individuals and society (Allan 2013a; 2013b).

Accordingly, virtual water *'trade'* refers to the 'exchange' of water in virtual form – that is 'embedded' in the traded commodities as a factor of production – between different trade partners. The economic rationale behind the virtual water concept is consistent with international trade theory and the Heckscher-Ohlin tradition of economic thought (Reimer 2012), and highlights the role of the opportunity cost of water in promoting an efficient allocation of scarce resources (Bouwer 2000). Applied to the MENA economies, virtual water 'trade' has not only drawn attention to the invisible political economy processes through which the region's economies have managed to cope with water scarcity over the past half century, but it has also explained the absence of conflicts over water in the region (Allan 1998b). The terms 'trade', 'flows', 'imports' and 'exports' when associated with virtual water will be used throughout the study with inverted commas, the reason being that, as pointed out by Merrett (2003a) it is in fact goods that are being traded, not water.

Virtual water generally ‘flows’ from “comparatively advantaged regions, where there is a surplus of soil water in soil profiles to comparatively disadvantaged regions, such as the MENA region where water is scarce” (Allan 1998 in Wichelns 2001: 133). Many water scarce countries are, however, virtual water ‘exporters’ the reason being that water resources tend to be either under-priced from a societal point of view or not priced at all (Reimer 2012). The volume of virtual water ‘flowing’ between nations at the global level as a result of trade in agricultural and industrial products was 2,320 Gm^3/yr, in the period 1996-2005 (Hoekstra and Mekonnen 2012).

It has been argued that the ‘import’ of virtual water represents a fundamental “exogenous” source of water for water-scarce countries (Haddadin 2003). The levels of food imports in the MENA region suggest that the water stress is currently addressed and solved *outside* the water sector (Allan 2001). The study will show that this strategy has been particularly pertinent over the past decades thanks to a downward trend in the price of food commodities, which has lasted until the mid 2000s. International virtual water ‘trade’ is a fundamental aspect of the region’s food security: the region has been importing nearly 40 million tonnes of cereals and flours yearly since the late 1980s (Allan 1999a). In 1997 the import of grain by the MENA countries accounted for about 25% of the world’s import of grains (Brown and Halweil 1998). As Allan (1999a: 1) put it, “More virtual water ‘flows’ into the region each year than flows down the Nile into Egypt for agriculture”.

Despite its hydropolitical significance, the role that virtual water ‘trade’ plays in curbing the demand for domestic water and in mitigating the effects of water scarcity is scarcely acknowledged in public debates in the MENA. This market-mediated mechanism has been defined as “economically invisible and politically silent” (Allan 2001; 2002; 2005). This invisibility and silence of virtual water ‘trade’ has hidden the scale and strategic significance of the local water deficits. The MENA societies and governments have adopted the virtual water ‘trade’ remedy to water scarcity without being aware of the numerous problems avoided and the even more numerous potential problems associated with the assumption that cheap food will always be available.

The imperative to import water-intensive food commodities proved to be a painless political economy process in a world of low and declining food prices, and was further fuelled by rising oil revenues in the 1970s (Hakimian 2003). The long-run downward trend in food prices has been facilitated by the highly subsidised agricultural production costs of the major grain exporters – the US and the EU – and resulted in "exceptionally 'favourable' supply side conditions" for the MENA economies (*ibidem*: 4). Over the past decade, however, it has become evident that a number of global pressures are making it unlikely that food prices will continue to fall. Demand for bio-production driven by demography, by the diversion of crops to energy production and by the need to reverse the impacts of past and current irrigated farming on the water services of the environment are together changing the dynamics of global food markets. These new dynamics could spell serious political consequences in what is already a politically unstable region.

The 2007-2008 and the 2011 spikes in food prices witnessed the vulnerability of large food importers to the oscillations and distortions of global markets. Over these years, the MENA economies experienced the difficult combination of sudden export restrictions and soaring food bills, which resulted in an increased pressure on public finance and consumers' expenditure on food. These factors spurred civil unrests and turmoil in some of the region's countries. These changing conditions for importing food (and virtual water) are likely to affect the less diversified economies in the region, preventing their capacity to achieve food (and water) security through reliance on international trade.

1.3.2 Objectives of the study and contribution to the existing literature on the MENA region

Since its inception, the virtual water concept has generated flourishing literature, which has considerably increased over the past few years. It has also had a variety of applications, the most fortunate of which is the concept of *water footprint*, developed by Arjen Hoekstra at the UNESCO-IHE Institute for Water Education in the early 2000s (Hoekstra 2003). The concept can be usefully applied to understand the appropriation of water resources by a nation, and also the impacts of this consumption on global water resources (Chapagain 2008). A number of analyses have been developed since its inception both at the national and international level (among others, Chapagain and Hoekstra 2004; Hoekstra and Chapagain 2007; Chapagain 2008; Hoekstra and Chapagain 2008; Mekonnen and Hoekstra 2010a, 2010b, 2011a, 2011b, 2012).

The theoretical foundations and policy relevance of the virtual water concept are still quite hotly debated (Ansik 2010; Gawel and Bernsen 2011a, 2011b; Merrett 2003a; Wichelns 2009, 2010a, 2010b, 2011). The political nature of water allocation, management and policy in the MENA region has been variously addressed and understood (among others, Allan 1996, 1997, 1998, 1999a, 1999b, 1999c, 2001, 2003a, 2003b 2009; Allan and Olmsted 2003; Nicol and Cascao 2011; Trottier 1999; Zeitoun and Warner 2006; Zeitoun 2009; Zeitoun *et al.* 2010; Zeitoun *et al.* 2011; Zeitoun *et al.* 2012). A few studies have analysed virtual water 'trade' in some of the region's economies (Jobson 1999; Wichelns 2001; Yang and Zehnder 2002; Hakimian 2003; Yang *et al*. 2003; Elhadj 2004; Nassar 2007; Yang *et al.* 2007; Chahed *et al.* 2008; El-Fadel and Maroun 2008; Nazer *et al.* 2008; El-Sadek 2010; Faramarzi *et al.* 2010; Zeitoun *et al.* 2010; Chahed *et al.* 2011; Mourad *et al.* 2010; Antonelli *et al.* 2012; Choucane *et al.* 2013; Soltani 2013; Mohammadi-Kanigolzar *et al.* 2014).

The existing literature on the MENA region has thus far lacked a *comprehensive* investigation of the nexus between water, food, and trade in the region. The aim of this study is to advance knowledge in this field and also to provide policy-relevant insights and recommendations. The study will draw attention to the political economy processes that determine, and will determine in the future, the region's food-water security, and that go beyond the traditional concerns of water professionals and scientists. These perspectives will inform both water users and policy-makers on the available options to current water allocation and management and offer new ways to achieve the sustainable use of water resources. This study aims to fill this gap by answering a number of interrelated questions, such as: *How do the region's endowments contribute to the water and food security of their populations? What is the role of trade in underpinning water and food security, and what enables the region's economies to cope with the water deficit?*

The purpose of the study is to answer these questions by investigating the very dynamic relationship between water, food and trade in the region. The study will, first, assess the capacity of MENA economies to meet their food needs; secondly, shed light on the political economy processes underlying water and food security in the region; and thirdly, unravel the sources of water 'embedded' in international agricultural trade in order to discuss the role and significance of these source of water for the MENA water and food security. Finally, the study will show that water security is less dependent on a country's water endowments than it is on its socio-economic strength and diversification, which are the main determinants of how available water is used.

Consistent with the above, the overarching research question of the study is: **How have the MENA economies coped with water scarcity?** And more specifically: **How have these MENA economies achieved their water and food security?** A number of subsidiary questions and sub-questions have been identified and will be presented in more detail in Section 1.5.

The analysis conducted in the study is exploratory for three main reasons. First, the research will advance existing knowledge on water scarcity in the MENA region by considering *all* sources of water involved in food production, that is *blue* (surface and ground-) water, sustaining irrigation, but also *green* (soil) water resources, which underpin rainfed crop production and grazing. The MENA region is not rich in green water resources but they do provide a substantial proportion of the water used in food production. Secondly, the study will advance knowledge on the way the MENA countries have coped with water scarcity and managed to meet the requirements of their populations over recent decades, by providing a *comprehensive* analysis of the water-food-trade nexus in the region.

Thirdly, the study is original in that it will unravel the role that the different sources of water (namely, green and blue water resources) play in virtual water 'trade' in the MENA region and highlight their contribution to the region's water and food security. Some limitations of the present study should also be acknowledged. Among others, these limitations include lack of consideration of environmental sustainability deriving from water quality as well as control of water pollution in the MENA economies. The next section delimits the research in space and time.

1.4 Geographical and historical scope

For the purposes of this study, the Middle East and North African region extends from Morocco (west) to Iran (east), and from Turkey (north) to Yemen (south). In alphabetic order, it consists of Algeria, Bahrain, the Arab Republic of Egypt (hereafter referred to as Egypt), the Islamic Republic of Iran (hereafter referred to as Iran), Iraq, Israel, Jordan, Kuwait, Lebanon, Libya, Morocco, West Bank and Gaza (also referred to as Occupied Palestinian Territories or OPT), Oman, Qatar, Saudi Arabia, the Syrian Arab Republic (hereafter referred to as Syria), Tunisia, Turkey, the United Arab Emirates, and the Republic of Yemen (hereafter referred to as Yemen). This classification includes the MENA developing countries as classified by the World Bank excluding Djibouti (World Bank online database 2012a), and the higher-income water-scarce countries of Israel, the Gulf Cooperation Council countries, and Turkey.

The geographical scope of the study is illustrated in Figure 1.1.

Figure 1.1 The Middle East and North Africa

Source: Author

The region is wide and heterogeneous.. For the purposes of this study, the MENA economies are classified according to the human development categories developed by UNDP (2013) based on the Human Development Index (HDI), which is a composite index measuring a country's average achievements in three basic dimensions of human development. The region's economies are classified into very high, high, and medium human development (Table 1.1).

This classification has been preferred to the World Bank's income-based classification of the region's countries, as the HDI complements this economic indicator by including also non-income components that influence the level of human development. The three dimensions captured by the HDI are: health conditions, measured as life expectancy at birth; education conditions resulting from mean years of schooling and expected years of schooling; and living standards, measured as the GNI per capita (PPP $). The study deploys this categorisation as it is argued that socio-economic development in the region shape water outcomes far more than local water endowments.

Table 1.1 Classification of MENA countries by HDI

Categorisation	Country	HDI rank	Values
Very High	Israel	16	0.900
	Qatar	36	0.834
	UAE	41	0.818
High	Bahrain	48	0.796
	Kuwait	54	0.790
	Saudi Arabia	57	0.782
	Libya	64	0.769
	Lebanon	72	0.745
	Iran	76	0.742
	Oman	84	0.731
	Turkey	90	0.722
	Algeria	93	0.713
	Tunisia	94	0.712
Medium	Jordan	100	0.700
	OPT	110	0.670
	Egypt	112	0.662
	Syria	116	0.648
	Morocco	130	0.591
	Iraq	131	0.590
Low	Yemen	160	0.458

Source: Elaboration based on UNDP 2013

The MENA countries will also be classified throughout the study, according to their oil-resource endowments, into two groups:

- **Oil-exporting economies**, including the GCC countries (Bahrain, Kuwait, Qatar, Oman, Saudi Arabia and the UAE), Iran and Iraq in the Near East, and Algeria and Libya in North Africa;

- **Oil-importing economies**, including Egypt, Jordan, Lebanon, Syria, Morocco, Tunisia, West Bank and Gaza.

Although Egypt and Syria export oil, their exports do not exceed 80% of domestic consumption as in the other countries classified here as 'oil exporters' (Minot *et al.* 2010). The temporal focus of the study is the second half of the last century until the present day. The MENA region entered its water and food insecurity between the 1950s and the 1970s at a point in history when the global prices for staple foods were at an historic low and were continuing to decline. Allan suggested that, in terms of food self-sufficiency, the region as a whole "ran out of water in the 1970s" although "the news of this important economic fact has been little exposed" (1997b: 3). As agricultural production has been the major consumptive use of water, the level of food imports can be effectively used as an indicator of the scale of a country's water deficit (*ibidem*). As basic grains are traditionally at the core of calls for food self-sufficiency, the trends in the import of grain of the MENA economies can be deployed to show the region's reliance on trade for its food security. Reliance on international trade is essential for the region's food security not only to cope with future trends of food demand and supply in the long term, but also in the face of the variability of local supplies in the short term (Lofgren and Richards 2003).

1.5 Preliminary research questions and hypotheses

This section outlines the main research questions, sub-questions and hypotheses of the study. A more extensive explanation is provided in Chapter 3. The overarching research question is: **How have the MENA economies coped with water scarcity?** And more specifically: **How have these MENA economies achieved their water and food security?**

First subsidiary question**:** To what extent can local water resources meet the food-water requirements of the MENA political economies*?*

Sub-questions:

1.1 To what extent is the MENA region facing a water challenge?

1.2 How is the MENA region endowed with food-water resources? To what extent can local water resources meet the region's requirements for food production?

Main hypothesis: The MENA countries face food-water scarcity, although to different extents, as the water available locally is less than the water requirements for securing the production of an adequate daily calorific intake per person of a balanced diet. This question is addressed in the background chapter and the first analytical chapter of the study (Chapter 3 and 5).

Second subsidiary question: What has been the role of international trade in meeting the water requirements of the MENA economies? To what extent have the MENA countries relied on virtual water 'trade' to secure their food-water needs?

Sub-questions:

2.1 To what extent is freshwater appropriation related to the consumption of agricultural goods in the MENA region? What is the contribution of water resources from outside the region to the region's water footprint?

2.2 How has virtual water 'trade' in agricultural commodities evolved over the past three decades, both globally and in the MENA region?

2.3 What has been the structure of virtual water 'trade' in the MENA over the past three decades? That is, to what extent do the MENA countries 'exchange' virtual water between themselves and with the rest of the world?

2.4 Which have been the main virtual water 'trade' partners of the MENA economies?

2.5 To what extent have the MENA countries been 'net importers' of virtual water? To what extent are they dependent on virtual water 'imports' to secure their food needs?

Main hypothesis: The MENA countries are largely dependent on virtual water 'imports' of agricultural commodities. Population growth and changes in dietary preferences have driven an increase in the agricultural water footprints and in virtual water 'imports'. There is a correlation between virtual water 'import' dependency, socio-economic diversification and adaptiveness, food security and mineral resource endowments. This hypothesis will be tested in Chapter 6.

Third subsidiary question: To what extent have green and blue water resources underpinned the MENA virtual water 'trade'?

Sub-questions:

3.1 How has green and blue virtual water 'trade' in agricultural commodities evolved over the past three decades, both globally and in the MENA region?

3.2 What has been the structure of green and blue virtual water 'trade' in the MENA economies over the past three decades? That is, to what extent have the MENA countries 'exchanged' green and blue virtual water between themselves and with the rest of the world?

3.3 Which have been the main green and blue virtual water import 'trade' partners of the MENA economies?

3.4 To what extent has the MENA 'exported' virtual water in the different types of agricultural commodities? Which have been the main "channels" of virtual water 'outflows' from the region's economies?

3.5 To what extent have the MENA countries been 'net importers' of green and blue virtual water?

Main hypothesis: The largest share of the virtual water 'flowing' to the MENA political economies is 'embedded' in traded commodities is *green water*, as the region's trade partners mainly produce under rainfed conditions. The reliance on blue water resources for producing agricultural commodities for export is relatively higher in the MENA economies than in their virtual water 'trade' partners. This question is addressed in the last analytical chapter (Chapter 7).

1.6 Structure of the study

The study is divided into three main parts and includes eight chapters. The first part provides background information on the research context (Chapter 2). The following part presents the theoretical and the methodological frameworks guiding the study, the research questions, sub-questions and hypotheses (Chapters 3 and 4). The third part includes three analytical chapters (Chapters 5-7) and the Conclusion (Chapter 8). What follows summarises the aims and contents of each chapter.

Part I – BACKGROUND

Chapter 1 - Introduction

The chapter presents the research problem and provide background information on the research setting. The objectives of the study and its contribution to the existing literature on the topic addressed are also presented.

Chapter 2 - The Research Context

This chapter provides an extensive overview of the research context. It outlines the main environmental, socio-economic and political challenges the MENA region is currently facing *vis-à-vis* its water resource endowments. Special attention will be given to the agricultural sector and the problems associated with water allocation, management and policy in the region.

Part II – RESEARCH FRAMEWORKS

Chapter 3 - Theoretical Framework

This chapter presents the theoretical frameworks and relevant concepts informing the study that support the analysis carried out in the analytical chapters. The study is anchored in the *virtual water* concept. The chapter will provide an overview of the theoretical foundations of the concept by discussing its relationship with the tradition of Political Economy and International Trade Theory. It will also review the concepts of *water security* and *social adaptive capacity*, and discuss their relevance for the study. Finally, the research questions, sub-questions and hypotheses of the study are presented.

Chapter 4 - Methodological Approach

This chapter outlines the methodological approach, as well as the techniques (methods) employed throughout the study to answer the research questions and test the related hypotheses. The limitations of the study are also identified and discussed.

Part III – ANALYTICAL CHAPTERS

Chapter 5 - Food-water scarcity in the Middle East and North African region

The first analytical chapter analyses the water-food nexus in the MENA region by providing an assessment of water availability for food production in the region's economies. The assessment includes all the sources of water involved in food production, that is the surface and groundwater resources supporting irrigated farming, and the water stored in the root zone, which, becoming soil moisture, underpins rainfed agriculture. Although it underpins the largest share of global food production, soil - or green - water is usually ignored in conventional water scarcity assessments as well as by policy-makers in the region. The potential for improving the efficiency of rainfed farming, in conjunction with land management, will be emphasised.

Chapter 6 - Virtual Water 'Trade' in Agricultural Products in the Middle East and North African region

The aim of the second analytical chapter is to investigate the nexus between water, food and trade in the MENA region. The analysis provides a quantification of the virtual water 'flows' associated with trade in agricultural commodities, distinguishing between crops, high-value food products, animal-based products and non-edible agricultural commodities. The analysis will draw attention on the extent to which the region depends on virtual water 'trade' to meet its water-for-food requirements, and also highlight the relationship between water scarcity in the region, socio-economic adaptiveness and virtual water 'imports' in the MENA countries.

Chapter 7 - Green and Blue Virtual Water 'Trade' in the Middle East and North African region

This chapter analyses the sources of water 'embedded' in the MENA virtual water 'trade' in order to discuss the role and significance of international agricultural trade, which entails an invisible 'exchange' of water resources at the global level. The chapter will shed light on the *invisible* role that *green* (soil) water plays in underpinning food security in the MENA region, as opposed to surface and groundwater bodies (*blue* water), which support irrigated agricultural systems.

Chapter 8 - Conclusions

This chapter draws some conclusions and provides some final remarks. It discusses the study's contribution to the literature on the topic investigated, the main findings of the research and the extent to which they corroborate or refute the initial hypotheses. The chapter finally identifies the strengths and limitations of the study, and sets the ground for future research. The study limitations derive both from the boundaries of the research but also from its assumptions, data availability and database quality. One of the major limitations of the study is that the research does not include consideration of environmental sustainability in the MENA based on water quality standards as well as limits for water pollution levels.

2. The Research Context: Political Economy of Water Resources in the MENA region

2.1 Introduction

The purpose of this chapter is twofold. First, it will seek to provide background information and context on the main environmental, economic and political factors that make the MENA water question particularly urgent. Secondly, the chapter aims to set the scene for the analysis developed in the analytical Chapters 5, 6, and 7.

The chapter is organised as follows. The next section (2.2) briefly surveys the environmental and hydrological setting of the research. Section 2.3 is concerned with water-related problems and the political economy trends and dynamics that have determined, and will in the future, the region's demand for water. These driving forces are mainly the increasing demand for food associated with population growth; rapid urbanisation; and the advancement of the economy and the associated changes in living standards. The following section (2.4) deals with the way water-related problems are addressed and solved in the MENA region. The significance of virtual water 'trade' for the region's water and food security is addressed in this section, as well as the role that politics plays in shaping water policy. The final section (2.5) draws some conclusions on the basis of the review of the relevant literature on the MENA region and provides some preliminary insights on the main contributions of the study.

2.2 Environmental and hydrological setting

This section presents the environmental and hydrological setting of the study. The following sub-questions will address the MENA geographic and climatic characteristics, discuss the potential impacts of climate change, and outline water resource supplies in the region.

2.2.1 Geography and climate

Geography and climate are not only key determinants of water availability and accessibility, but also exert constraints on agricultural production. The MENA region enjoys and endures diverse climatic conditions. The region's economies have to manage the difficult combination of very low and highly variable annual precipitation. There are also considerable disparities between countries (FAO 2002; World Bank 2007). Rainfall generally occurs during winter and the summer dry period lasts for 5-9 months (IPCC 1997b). As shown in Figure 2.3, the region's lands are classified as semi-arid, arid and hyper-arid (WRI 2002). The region can be grouped into four areas on the basis of the geographical and climatic conditions. These sub-regions are: the Arabian Peninsula; Iran; the Near East; and North Africa. The classification adopted and the description that follows is based on FAO (2005; 2008b). Table 2.1 summarises the main geographic and climatic characteristics of the identified sub-regions.

The Arabian Peninsula is the largest sub-region of the MENA. It extends over 3.1 million km² and is bordered by Jordan and Iraq (north); the Persian Gulf and the Gulf of Oman (east); the Arabian Sea and the Gulf of Aden (south); the Red Sea and Egypt (west). It consists of seven countries: Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, United Arab Emirates, and Yemen. Saudi Arabia covers almost 70% of total area and encompasses the largest sand desert in the world, the Rub Al–Khali (Almazroui *et al*. 2012). The climate of the Arabian Peninsula is arid and hyper-arid (WRI 2002). The area is the driest in the Middle East: average precipitation is 117 mm/year. Mainly as a consequence of the severe water scarcity, cultivated land accounts for only 5% of cultivable land (FAO 2008b).

The Islamic Republic of Iran is unique in its geographic and climatic conditions. FAO (2008b) considers it separately from the other sub-regions of the Middle East. Iran comprises an area of 1.7 million km² with altitudes varying from -40 m to 5670 m. Altitude consistently affects the county's climate, which is extremely variable from north to south, and is characterised by extremely hot temperatures in summer months and very low temperatures in winter, especially in the northwest. Average annual precipitation is 228 mm and 90% of the country is arid or semi-arid. In 2005, cultivated land accounted for about 18 million ha, out of a total cultivable area of 51 million ha.

The Near East comprises an area of about 1.5 million km² and is bordered by the Black Sea and the Caucasus (north); Iran (east); Kuwait and Saudi Arabia (south); and Egypt and the Mediterranean Sea (west). The sub-region comprises Iraq, Israel, Jordan, Lebanon, the Occupied Palestinian Territory, Syria and Turkey. Climate is generally arid or semi-arid. Annual average precipitation in the region is 440 mm, with significant variation between countries. Jordan is the driest country in the area; Lebanon and Turkey are the rainiest. The average annual precipitation in these countries is 100 mm, 823 mm, and 643 mm respectively. In 2005, cultivated land accounted for 84% of total cultivable area (FAO 2008b).

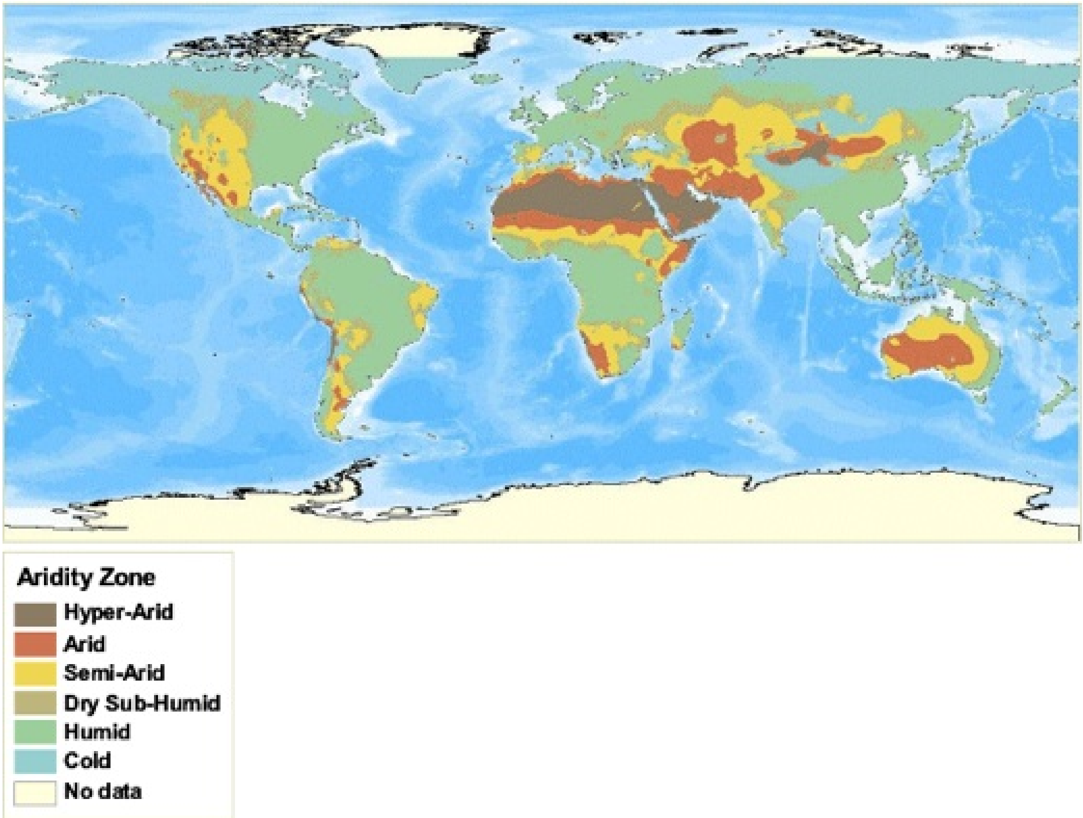
North Africa consists of Algeria, Egypt, Libya, Morocco, and Tunisia. It covers an area of 6 million km² that corresponds to about 19% of the continent. The sub-region's countries are bordered by the Mediterranean Sea to the north and the Sahara to the south. Proximity to the sea has strong impacts on the climate, which is moderate in the north and very dry in the south. Average precipitation is 96mm per year, but there are significant disparities between countries. In 2005, cultivated land accounted for 43% of total cultivable area (FAO 2005).

Table 2.1 Geographic and climatic characteristics of the MENA sub-regions

	Countries	**Climate**	**Total area** [km²]	**Cultivable area** [Thousand ha]	**Cultivated area** [Thousand ha]	**Cultivated area** [% of cultivable area]
Arabian Peninsula	Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, United Arab Emirates, Yemen	Arid and hyper-arid	3 100 290	58 967	2 734	5%
Iran	Iran	Arid and semi-arid	1 745 150	51 000	18 107	36%
Near East	Iraq, Israel, Jordan, Lebanon, OPT, Syria, Turkey	Arid and semi-arid	1 533 030	47 304	39 570	84%
North Africa	Algeria, Egypt, Libya, Morocco, Tunisia	Arid and semi-arid (north); hyper-arid (south)	5 752 890	65 320	28 028	43%

Source: Elaboration based on FAO 2005; 2008b and WRI 2002

Figure 2.3 Map of aridity zones in the world



Source: WRI (2002)

2.2.2 Climate change

Water and climate are inextricably linked. Water resources are fundamentally involved in all components of climate systems (atmosphere, hydrosphere, land surface and biosphere). Any change or variation in climate will thus affect the hydrological cycle and hydrological systems (Kumar 2012). The main climate drivers for water resources availability and accessibility are precipitation, temperature and evaporative demand. These are also key controllers of agricultural production. As such, climate change has the potential to increase further the competition over water resources in water-short countries, and to exacerbate other environmental, social and economic challenges. The poorest countries and populations of the world will bear the greatest costs of climate change (Stern 2007).

The need for crafting adaptation strategies and build institutional capacity to cope with climate change, at the regional, national and local level, has been emphasised (Huq *et al.* 2003; USAID 2007; FAO 2009a, 2009b; World Bank 2010; WRI 2012). This statement applies more forcefully than anywhere else to the MENA region, which is already one of the most water scarce regions in the world (Gleick 2000; Roudi-Fahimi *et al.* 2002; World Bank 2009b). The region is in fact particularly vulnerable to climate change and has rising populations (Sowers *et al.* 2011). This combination is likely to affect both the quantity and quality of water resources, and to pose difficult challenges for water planning, management and policy.

Climate change has been defined by the UN Intergovernmental Panel on Climate Change (IPCC), as "a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer" (2008: 30). According to the IPCC, climate change has already impacted the world's water resources. It has been associated with changes in precipitation patterns and intensity; increased risk of extreme events; increased water vapour in the atmosphere and evaporation; and reduced soil moisture and runoff which have been observed over the past five decades.

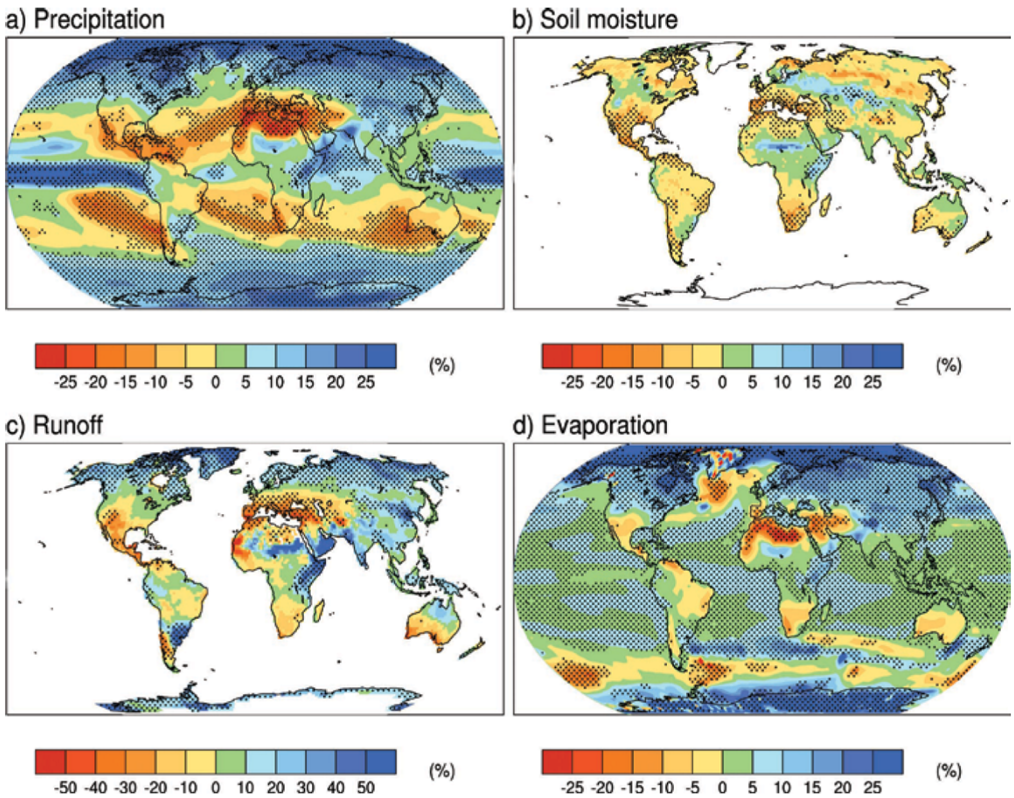
Climate models generally predict an increase in precipitation in temperate and high latitude regions, and a decline in lower latitudes. By altering temperature, precipitation and evaporative demand, climate change will substantially accelerate or intensify the hydrological cycle (Huntington 2006). Although it is often difficult to distinguish human-induced changes in climate from natural variations (Adger *et al.* 2003), the scale and direction of the predicted changes in temperature are relatively certain (Chenoweth *et al.* 2011). Prediction of future trends in rainfall is, however, uncertain. From a global perspective, it is "very likely" that the costs of climate change in terms of water supply will outweigh the benefits (IPCC 2008: 44).

Climate change is expected to affect both the MENA environmental and socio-economic conditions. Its effects are likely to affect first and foremost the agricultural sector, which consumes over 80% of the region's water (Zeitoun *et al.* 2010). Climate simulations indicate a decline in agricultural productivity by 8.13% for each degree increase in temperature, as a result of the reduced water availability and labour productivity (Roson and van der Mensbrugghe 2012). The effects of climate change in the region will also exacerbate soil degradation and accelerate desertification, with a corresponding reduction in cultivable land (Drine 2011), and deteriorate water quality thus further limiting water availability (Sowers *et al.* 2011; Tropp and Jägerskog 2006). The projected reduction in yields is estimated to be higher than the global average: roughly 33% in rice, 7% in wheat, 8% in maize, and 4% in millet (Nelson *et al.* 2009). The region's potential GDP is expected to deviate by -9.58% by 2100 due to climate change impacts on economies (Roson and van der Mensbrugghe 2012).

By 2050, Algeria, Egypt, Morocco, Syria and Tunisia will experience the most severe water shortages in the region as a direct consequence of climate change (FAO 2002). The development of adaptation strategies is likely to be particularly challenging in Turkey and Syria, where the employment in agriculture is high; Iraq, as a consequence of the expected magnitude of climate change; and Jordan, which is already facing severe problems because of its very limited water resources (Chenoweth *et al.* 2011). The adoption of water demand management policies has the potential to act as a buffer against the predicted climate-induced impacts on the already stressed water resources and food systems of the MENA (Zeitoun *et al.* 2010). However, the promotion of adaptation strategies is still a low priority for local policy-makers (Sowers *et al.* 2011).

Figure 2.2 illustrates climate change impacts on precipitation, soil moisture, runoff, and evaporation for the period 2080-2099, showing the negative hydrological and water resource futures for the MENA region, as projected by the IPCC (2008). Table 2.2 summarises the expected impacts of climate change on the MENA countries. In some parts of the Middle East, climate projections indicate an increase in precipitation, which, however, is likely to be countered by the increase in temperature and evaporation (IPCC 1997c). The risk of floods and droughts in the region will increase as a result of the increased variability and intensity of precipitation, and the duration of dry seasons. Groundwater recharge rates are expected to decrease by more than 70% by 2050 in the southern rim of the Mediterranean, and to increase by about 30% in the Near East by the same year (IPCC 2008).

Figure 4.2 Predictions of climate-induced changes in precipitation, soil moisture, runoff and evaporation for the period 2080-2099



Source: IPCC (2008: 27)

Table 2.2 Climate-induced changes in precipitation, soil moisture, runoff and evaporation for the period 2080-2099 in the Middle East and North Africa

	Precipitation	**Soil moisture**	**Runoff**	**Evaporation**
Middle East	-15% to + 20%	-15% to +5%	-40% to +50%	-15% to +10%
North Africa	-25% to -5%	-15% to -5%	-40% to -10%	-25% to -50%

Source: Elaboration based on IPCC 2008

2.2.3 Water endowments

The MENA region is widely acknowledged as being one of the most water scarce regions in the world. Twelve of the world's fifteen water-short countries are in the region (Gleick 2000). Per capita freshwater availability decreased from 4,000 m^3 per year in 1950 to 1,100 m^3 in 2007 (World Bank 2007). The situation will worsen. Projections of future water availability indicate that two thirds of the region's countries will have less than 200 m^3 per capita by 2040-2050 (Immerzeel *et al.* 2011). The following sub-sections will outline the water resource situation of the MENA region.

2.2.3.1 Renewable freshwater

Renewable freshwater availability in the region is very low relative to other regions. In 2009, renewable internal freshwater resources in the MENA was 616 m^3/cap/year, as against 1236 m^3 in South Asia; 8071 m^3 in Europe and Central Asia; 23105 m^3 in Latin America and the Caribbean; and 4685 m^3 in East Asia and the Pacific (World Bank 2012a). Within the region, there are huge disparities between countries. As shown in Table 2.3, water is relatively abundant in Turkey, Iraq, Iran and Lebanon (total renewable water is above 1000 m^3/cap/year); scarce in Morocco, Syria, Egypt and Oman (total renewable water ranges between 500 and 1000 m^3/cap/year); and extremely scarce in the rest of the countries (total renewable freshwater is below 500 m^3/cap/year). The Gulf States and Yemen are the scarcest in the region (FAO AQUASTAT 2012).

Vulnerability occurs where water resources are sufficient at the national level, but highly variable in time and space. According the World Bank (2007), the countries facing vulnerability are mainly Algeria, Iran, Lebanon, Morocco, Tunisia and the West Bank. Hyper-aridity occurs where renewable water resources are extremely low, as in Bahrain, Gaza, Jordan, Kuwait, Libya, Oman, Qatar, Saudi Arabia, the United Arab Emirates, Israel and Yemen. These countries generally depend on groundwater sources. The region's high-income economies also deploy *non-conventional water sources*, such as desalination of brackish or sea water, and re-use of wastewater (more details on desalination are provided below).

Table 2.4 shows total actual renewable water resources for the MENA countries, that is the maximum theoretical yearly amount of water actually available for a country. This figure is obtained by subtracting the overlap between surface water and groundwater resources from the sum of the two (FAOSTAT 2012). It should be noted that some countries have significant non-renewable water resources – notably Libya and Saudi Arabia.

Table 2.3 Total renewable water resources (actual) in the MENA countries (2008-2012)

> 1000 m³/cap/year	
Turkey	2936
Iraq	2387
Iran	1859
Lebanon	1065
500-1000 m³/cap/year	
Morocco	908
Syria	823
Egypt	706
Oman	503
< 500 m³/cap/year	
Tunisia	438
Algeria	329
Israel	240
OPT	207
Jordan	151
Libya	94
Bahrain	92
Saudi Arabia	87
Yemen	87
Qatar	33
UAE	20
Kuwait	7

Source: Elaboration based on FAO AQUASTAT 2012

Table 2.4 Renewable water resources (actual) in the MENA countries (2008-2012)

	Surface water total renewable [10^9 m³/yr]	**Groundwater total renewable** [10^9 m³/yr]	**Overlap between surface and groundwater** [10^9 m³/yr]	**Total Renewable** [10^9 m³/yr]
Algeria	10.15	1.517	0	11.67
Egypt	56	1.3	0	57.3
Libya	0.2	0.5	0.1	0.6
Morocco	22	10	3	29
Tunisia	3.4	1.595	0.4	4.595
Bahrain	0.004	0.112	0	0.116
Kuwait	0	0.02	0	0.02
Oman	1.05	1.3	0.95	1.4
Qatar	0	0.058	0	0.058
Saudi Arabia	2.2	2.2	2	2.4
UAE	0.15	0.12	0.12	0.15
Yemen	2	1.5	1.4	2.1
Iran	106.3	49.3	18.1	137.5
Iraq	74.33	3.28	2	75.61
Israel	0.555	1.225	0	1.78
Jordan	0.65	0.54	0.253	0.937
Lebanon	3.803	3.2	2.5	4.503
OPT	0.087	0.75	0	0.837
Syria	12.63	6.174	2	16.8
Turkey	173.8	67.8	28	213.6

Source: Elaboration based on FAO AQUASTAT 2012

2.2.3.2 Fossil and renewable groundwater sources

As shown in Table 2.4, the majority of the MENA renewable groundwater aquifers are located in North Africa, in the Eastern Mediterranean countries and the Gulf. These aquifers have supported the MENA human settlements for millennia, but since the second half of the 20th century, all these coastal aquifers have been subject to seawater intrusion due to over-use (Allan 1997a). Groundwater sources are referred to as *fossil* aquifers when dating of these water sources indicates that their emplacement occurred thousands of years ago. They are generally associated with very low rates of recharge and can be defined as an "economically recoverable 'stock', such as oil or minerals" (FAO 2008b: 34).

Over-pumping has progressively depleted this stock in the MENA region, as its economies and associated water needs, and technology developed. According to Woertz (2013), groundwater depletion in the Middle East is more pressing than transboundary water issues along the river basins of the Nile, Euphrates, Tigris and Jordan.

Allan (2007: 76) identified the three main problems associated with the MENA groundwater sources. First, renewable groundwater aquifers are "too easy to utilize and to damage" when a regulatory framework and a balanced approach to water resources is lacking. Second, fossil groundwater resources are expensive to develop and maintain both in terms of pumping and delivery systems to users. Thirdly, the region, with the exception of Israel, has not developed the regulatory culture and institutional capacity, which are necessary to address the problems associated with unsustainable groundwater-using practices for the collective interests of populations. These issues will be analysed in more detail in the following sections. An area that also deserves attention relates to the governance of groundwater quality. The regulation and monitoring of the water quality of aquifers is in fact generally poor, especially in Jordan, West Bank and Gaza, Syria and Lebanon (Tropp and Jä gerskog 2006; Allan 2001).

2.2.3.3 Soil water - green water

Soil water comes from rainfall and represents almost two thirds of the water that becomes accessible for natural and economic uses worldwide (Falkenmark and Rockström 2006; Hoff *et al.* 2010). In regions with temperate and humid climates, most water for food production originates from water in soil profiles. In areas of Europe and North America, very small proportions of the total national water budget – less than 10% – are required for supplementary irrigation (Allan *et al.* 2003). Soil water – also known as *green water* water underpins the largest share of food production globally (Fader *et al.* 2011; Hoekstra 2011).

The MENA region is probably the poorest inhabited region in the world in terms of soil water as it endures arid and semi-arid circumstances. According to Allan

(2001), soil water ranges from being relatively abundant in the northern part of the MENA region (Turkey, Syria and Iraq); negligible in Egypt and in the Arabian Peninsula. The volumes of soil or green water used for crop and livestock production across the region have had no metrics the mid 2000s, when Chapagain *et al.* (2005b) assessed the impacts of cotton production on water resources in the cotton producing countries. A few years later, Rockström *et al.* (2009) provided an assessment of global water availability for food production by including both green and blue water resources, under present and future scenarios of population growth and climate change (more details will be provided in Chapter 5).

This source of water has never been taken into account in the national water budgets of the MENA political economies, although it provides water for long established but non-optimum dryland winter farming and grazing. The adoption of more effective, wheat-medic-sheep rotations of dryland in the MENA region would increase agricultural output in dry years and increase yields threefold or more (Chatterton and Chatterton 1996). More effective utilisation of irrigation technologies would further improve yields and returns to scarce water.

2.2.3.4 Transboundary waters

Transboundary waters represent a major proportion of the MENA surface renewable water resources. Sharing, allocating and managing transboundary water in a sustainable way has been identified as one of the major water-management challenges of the region (World Bank 2007). The main transboundary rivers in the MENA are the Euphrates-Tigris, the Kura-Araks, the Asi-Orontes, the Jordan, and the Nile. Some aquifers in the region are transboundary. The main transboundary groundwater systems are: the Disi aquifers, shared between Jordan and Saudi Arabia; the Mountain Aquifer, shared between Israel and the occupied Palestinian Territories; and the North Western Sahara Aquifer System, shared between Algeria, Libya and Tunisia (SIWI 2009). There are other shared aquifers in the Arabian Peninsula. As shown in Table 2.5, the highest dependency ratios, indicating the share of total renewable water resources originated outside the country, are observed in Egypt (97%); Bahrain (97%); Kuwait (100%); Iraq (53%); Israel (58%); Jordan (27%); Syria (72%).

Table 2.5 Internal and external renewable freshwater resources, and dependency ratios in the MENA countries (2008-2012)

	Total *internal* renewable (actual) [10^9 m³/yr]	**Total *external* renewable (actual)** [10^9 m³/yr]	**Dependency ratio** [%]
Algeria	11.25	0.42	4
Egypt	1.8	55.5	97
Libya	0.6	0	0
Morocco	29	0	0
Tunisia	4.195	0.4	9
Bahrain	0.004	0.112	97
Kuwait	0	0.02	100
Oman	1.4	0	0
Qatar	0.056	0.002	3
Saudi Arabia	2.4	0	0
UAE	0.15	0	0
Yemen	2.1	0	0
Iran	128.5	9.015	7
Iraq	35.2	40.41	53
Israel	0.75	1.03	58
Jordan	0.682	0.255	27
Lebanon	4.8	-0.297	1
OPT	0.812	0.025	3
Syria	7.132	9.67	72
Turkey	227	-13.44	1

Source: Elaboration based on FAO AQUASTAT 2012

Note: Total internal renewable water resources is a long-term average annual flow of rivers and recharge of aquifers generated from endogenous precipitation. Actual External Renewable Water Resources is that part of the country's annual renewable water resources that are not generated in the country. This indicator is negative when the flow reserved to downstream countries is more than the incoming flow. The dependency ratio indicates the percent of total renewable water resources originating outside the country (FAO AQUASTAT 2014).

2.2.3.5 Dams

In the 20th century, as the MENA population and economy grew, much political energy and investment have been devoted to ensuring secure supplies and expanding water services. The MENA rivers are the "most heavily dammed in the world in relation to freshwater available" (World Bank 2007: xxii). The proportion of regional surface freshwater resources stored in reservoir exceeds 80% as against a global average of 10% (*ibidem*). As such, the scope for the construction of future dams is limited (Zeitoun *et al.* 2010). Total dam capacity in the Middle East is 843.9 km^3. Turkey, Iraq and Syria contain the largest total dam capacity in the area (FAO 2008b). North Africa has 230 dams and a total capacity of 194.03 km^3. The biggest reservoir in the world is the Aswan Dam in Egypt, which has a capacity of 162 km^3 (FAO 2005).

2.2.3.6 Non-conventional water sources

A significant share of the region's water supply portfolio for industrial and municipal use is provided by non-conventional sources of water, such as desalination of brackish or seawater, and wastewater treatment. As Table 2.6 shows, wastewater treatment and desalination of water are common practices almost everywhere in the MENA region. In 2008 total consumption of desalinated water in the Middle East accounted for 3.225 million m^3/year, with 87.4% of total use of desalinated water taking place in the Arabian Peninsula, 6.4% in the Near East and 6.2% in Iran (FAO 2008b). In North Africa, desalinated water accounted for 155.2 million m^3/year in 2005 and is produced in all the sub-region's countries (FAO 2005). A direct relationship has been found between income per capita and desalination capacity in the region. As Figure 2.3 shows, desalination capacity increases in direct proportion with GDP per capita (Fichtner and DLR 2011). Desalinated water investments are concentrated mainly in the oil-rich Gulf countries where over 65% of the world's desalination capacity had been installed by 2005 (Dawoud 2005).

Desalination capacity in the region is forecast to continue to grow steadily over the next decades (Fichtner and DLR 2011). Saudi Arabia is ranked first in the region, followed by the United Arab Emirates and Kuwait. By basically "turning oil into water" (Jones 2010: 6), Saudi Arabia has become a global leader in water desalination, with a production of 1 033 km^3/yr (FAO AQUASTAT 2012). Since

1990, more than half of the region's municipal water needs has been supplied by desalination (World Bank 2007). The cost of providing desalinated water to securie domestic, industrial sector and service sector water is economically sustainable for those living in strong and diversified economies; whereas, they are a problem for those living in weak and poorly diversified economies (Allan 2001).

Total treated wastewater in the Middle East accounts for 2 663 million m^3/yr. The Near East produces treats and reuses the largest share of wastewater in the Middle East (FAO 2008b). Annually, North African countries produce 5 963 million m^3/yr of wastewater (FAO 2005). Water re-use in irrigation is very significant in Egypt. It increases the water available at the field level by 40% (Allan 2001).

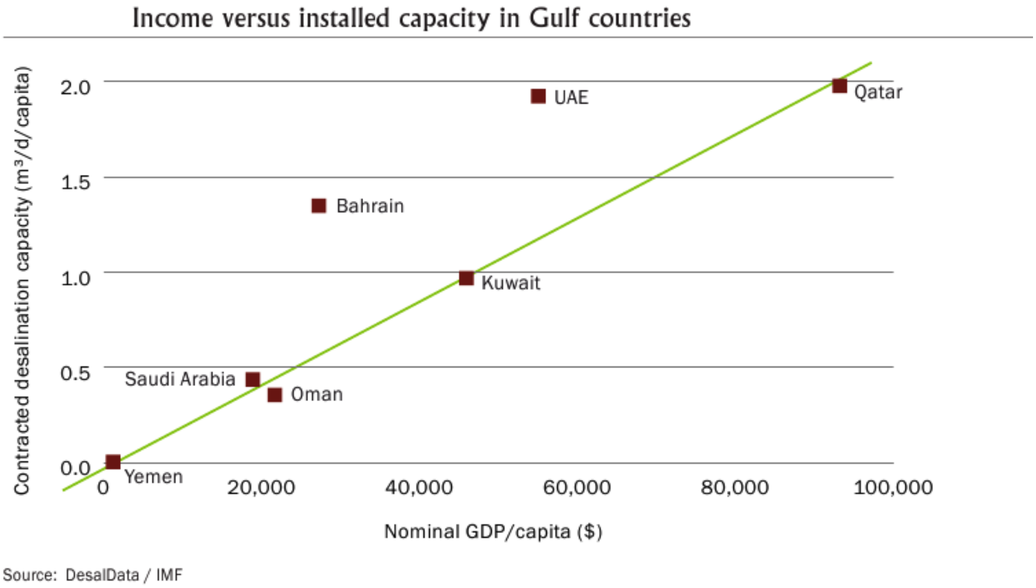
Table 2.6 Non-conventional water resources in the MENA countries[1]

	Desalinated water produced [10^9 m^3/yr]	**Wastewater** [10^9 m^3/yr]		
		Produced wastewater	**Treated wastewater**	**Direct use of treated wastewater**
Algeria	0.017	0.82	N/A	N/A
Egypt	0.1	3.76	2.971	2.971
Libya	0.018	0.546	0.04	0.04
Morocco	0.007	0.65	0.04	N/A
Tunisia	0.013	0.187	0.215	0.021
Bahrain	0.1024	N/A	0.0619	0.0163
Kuwait	0.4202	0.244	0.25	0.078
Oman	0.109	0.09	0.037	0.037
Qatar	0.18	0.055	0.058	0.043
Saudi Arabia	1.033	0.73	0.5475	0.166
UAE	0.95	N/A	0.289	0.248
Yemen	0.0251	0.074	0.046	0.006
Iran	0.2	3.075	0.13	0
Iraq	0.0074	N/A	N/A	N/A
Israel	0.14	0.45	0.283	0.2619
Jordan	0.0098	0.082	0.1074	0.0835
Lebanon	0.473	0.31	0.004	N/A
Syria	0	1.364	0.55	0.55
Turkey	0.0005	2.77	1.68	1

Source: Author (based on FAO AQUASTAT 2012)

[1] Data refer to the years 2003-2007. When they were not available, averages for the years 1998-2002 were deployed.

Figure 2.3 Desalination capacity and GDP per capita



Source: Fichtner and DLR (2011:2-8)

The recent history of desalination has been dramatic both in terms of technology and the cost of delivered water (Gilmont 2014b; Latteman *et al.* 2010; Latteman and Höpner 2008). The development of reverse-osmosis technologies in the late 1900s and their widespread adoption since 2000 has transformed the approach to the security of non-food water in the region. Costs of delivered water per cubic meter fell from US$ 1.5/m3 to US$ 0.56 for the Ashkelon plant in Israel in 2002 (Gilmont 2014b). Desalination along with wastewater re-use of municipal and industrial water have been shown to be essential elements of water security for some, and in due course for all, economies in the region.

2.3 Water resource problems

The previous sections of this chapter have outlined the environmental and hydrological setting of the research by discussing the MENA geographic and climatic features, and providing background information on the water resources of the region. The purpose of this section is twofold. First, to discuss the forces that drive, and will in the future, the demand for water resources and that shape the current approaches to water management in the region. Secondly it will present the challenges and problems associated with water resources allocation, management and policy.

2.3.1 Present and future forces driving demand

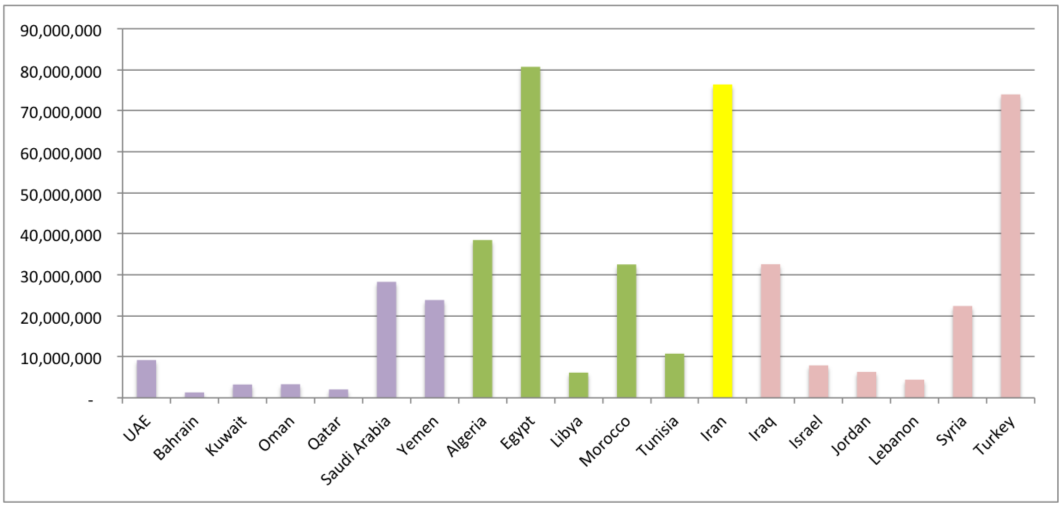
The MENA political economies are currently experiencing an upward surge in water demand that has the potential to exacerbate the region's water deficit. These driving forces relate mainly to population growth, urbanisation, increasing consumption associated with economic growth, and improvements in the standard of living. These forces make the ecologically and economically sound utilization of waters in the region very difficult (Allan 2001).

Future water demand scenarios predict that available surface and groundwater resources in the MENA will drop from 225,000 MCM/yr in the year 2000 to less than 190,000 MCM/yr in 2050. Blue water demand, on the contrary, will grow from 255,000 MCM/yr in the year 2000 to 450,000 MCM/yr in 2050, opening a gap of supply of 260,000 MCM/yr (Fichtner and DLR 2011). Water for domestic, industrial and service sector consumption require only about 5% each of the total blue and green water needed by an individual or a community. Only very few communities in the world cannot meet these requirements (Allan 2012). Current and future tensions in the MENA will concern the availability of water for food production, which requires about 90% of total water needs of an individual or a community (Allan 1997a; 1997b; 2001). The water scarcity predicament is compounded by large-scale water management problems, such as over-exploitation of aquifers, rationed water supply and sub-optimal irrigation services (World Bank 2007). Deteriorating water quality due to pollution and increasing levels of alkalinity and salinization are also apparent in a number of countries in the MENA, such as Syria, Lebanon and Jordan (Tropp and Jägerskog 2006). All these problems clearly affect human health, agricultural productivity and the ecosystem services of water (Immerzeel *et al.* 2011).

The major force driving water demand in the MENA is demography, coupled with changing consumption patterns, that is, an increased demand for water-intensive goods and services. Population is rising very rapidly in the region and consequently all the economies have had to mobilise more water to meet the needs of the additional consumers, especially in terms of food. The MENA has the second fastest growing population in the world (Roudi-Fahimi and Mederios Kent 2007), but contains only 1.4% of the world's renewable freshwater resources (Roudi-Fahimi *et al.* 2002). In 2002, the MENA population represented 6.5% of the world population, and 8.3% of the population in developing countries. The region's growth rate is 2% per year and is far above the average of the world's developing countries, except for Sub-Saharan Africa (Tabutin and Schoumaker 2005). Population growth is expected to aggravate water scarcity in the region more than climate than change (Gerten *et al.* 2011).

Thanks to declining death rates and slowly diminishing birth rates, population in the MENA has quadrupled during the second half of the 20th century. Total population stood at 104 million in 1950, it increased to 430 million in 2007 and is projected to reach nearly 700 million by 2050 (Roudi-Fahimi and Mederios Kent 2007). Average fertility currently stands at 3.4 children per woman and life expectancy is 69 years. The *demographic transition* of the MENA from high mortality and high fertility rates to low mortality and fertility started in the 1950s and the 1960s and is still underway. Although it began later than elsewhere, it is proceeding at a faster pace (Tabutin and Schoumaker 2005). The most populous countries in the region are Egypt, Iran, and Turkey (Figure 2.4). The Arabian Peninsula has a relatively small population but it has the fastest-growing populations in the region, with the largest proportion living in Saudi Arabia and Yemen (Roudi-Fahimi and Mederios Kent 2007).

Figure 2.4 Total population in the MENA sub-regions (2012)



Source: Elaboration based on UNPD 2014

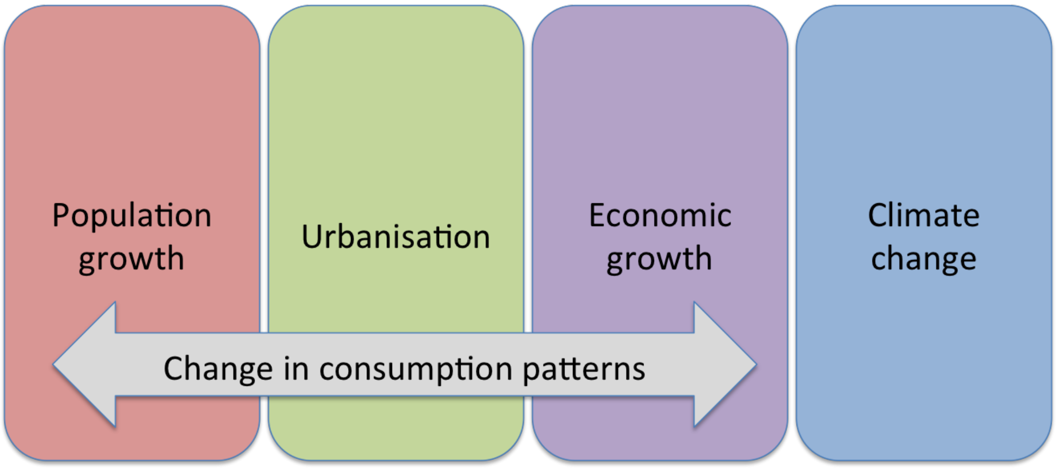
Urbanisation is a second driving force that will impact future water choices in the region, as most of population growth has occurred in urban areas (SIWI 2006). Urban population growth is, on average, 2.93% for the years 2005-2010. The share of urban population has doubled since the second half of the 21st century: it stood at 37% in 1950 and exceeded 73% in 2010. Future projections indicate that this proportion will reach 78% in 2025 and 83% in 2050. Qatar, Kuwait, Israel, and Bahrain were already more than 80% urban in the 1970s and are still the most urbanised countries in the region, followed by Lebanon, UAE, Jordan and Saudi Arabia (UNDESA 2011; Minot *et al.* 2010).

As in most developing countries, urban growth has been higher in small and medium-sized cities as compared to mega cities. The growth of small and medium-sized cities presents huge challenges for central and local governments as they generally have lower levels of services than bigger cities (SIWI 2006). Greater population density may enable communities to invest in more efficient and cost-effective water management but it is also likely to increase the demand for water, as urban populations tend to use more water than rural population (Roudi-Fahimi *et al.* 2002). As a result of the increase in urban population, subsidies for the provision of urban utilities have also grown (World Bank 2007). Most importantly, urbanisation is associated with a shift in consumption patterns, especially food consumption. Urbanites consume in fact a more diversified and water-intensive diet, with higher proportions of energy from fats, sweeteners and animal-based products (Popkin 2000).

A third driving force is the additional consumption associated with the advancement of the economy and associated uses of water, which rise as soon as economies begin to develop and the standard of living improves. However, progressive socio-economic development has the potential to transform and reform the MENA water management and policy, mainly by making the economic security of society less dependent on local water and agricultural livelihoods (Allan 2001). Decoupling of economic growth from natural resource consumption in Israel has recently been explored by Gilmont (2014a).

The combination of population growth, urbanisation, and economic development will inevitably increase water demands and lead to increased on water resources presently allocated to irrigated agriculture. The impact of these drivers is also be exacerbated by future climate-related risks, which are likely to impose further strain on the already severely stressed water and food systems in the region (Zeitoun *et al.* 2010). However, while the described forces driving demand may exacerbate the MENA physical water resource scarcity, the reasons for water problems lie elsewhere. As pointed out by Allan (2001), much more important than poor water endowments is the capacity of agricultural sectors, local governments and international institutions to respond and adapt to the resource scarcity. Figure 2.5 summarises the main drivers of water demands in the MENA.

Figure 2.5 Forces driving water demands

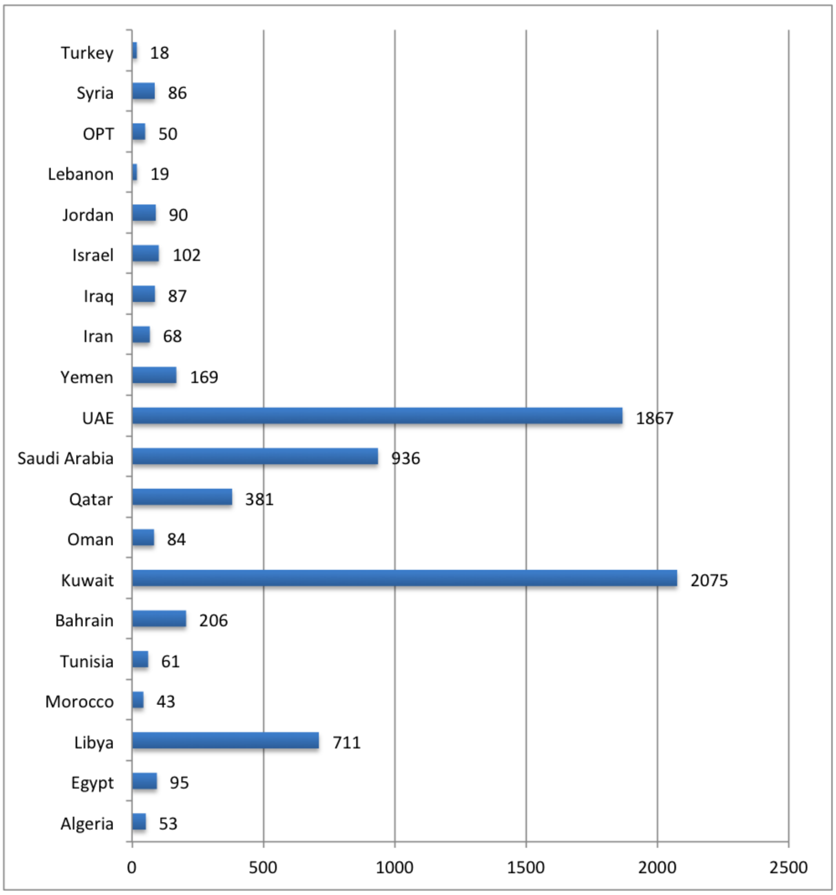


Source: Author

2.3.2 Water allocation and management

Water resources in the MENA are not only very limited but also heavily consumed. The region is currently using proportionately more of its renewable water resources than the rest of the world (World Bank 2007). The percentage of renewable freshwater withdrawn already far exceeds 100% in several MENA countries, such as Kuwait, United Arab Emirates, Saudi Arabia, Libya, Qatar, Bahrain, Yemen and Israel (Figure 2.6). Freshwater resources are persistently over-consumed both because of the low efficiency of water distribution systems, and partly because of the rapid growth of population and industrialisation in the region (Fichtner and DLR 2011).

Figure 2.6 Total actual renewable freshwater withdrawn (%)[2]



Source: Elaboration based on FAO AQUASTAT 2012

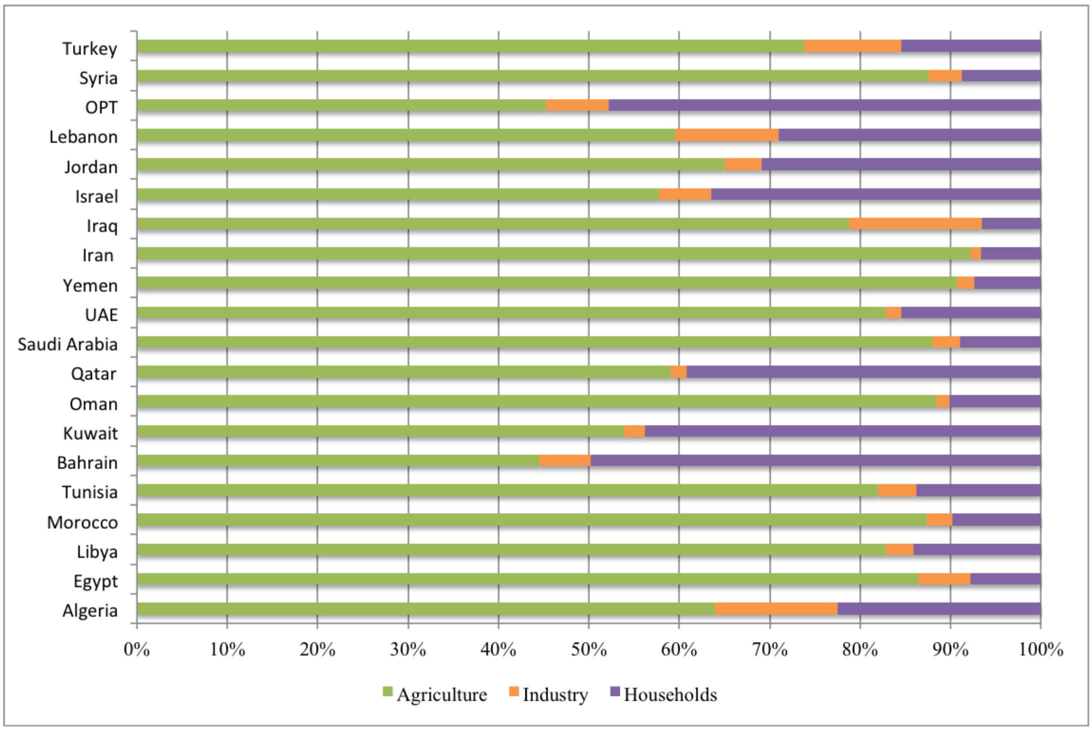
Agriculture is by far the biggest water user, accounting for more than 70% of water withdrawals globally (Molden 2007), and causes the most critical impacts on the water cycle of all anthropogenic activities (Baron *et al.* 2002; Falkenmark *et al.* 2004). Water problems are not only related to quantity but also quality of rivers, lakes and aquifers, mainly due to intensive use of fertilizers and weak environmental legislations throughout the region (Tropp and Jä gerskog 2006). Water withdrawals by agriculture reach up to 85% in North Africa, 86% in the Arabian Peninsula, 92% in Iran, and 68% in the Near East[3]. This proportion, however, varies greatly between countries. As shown in Figure 2.7, agricultural water withdrawal ranges between 44.5% in Bahrain and 92.1% in Iran. It exceeds

[2] All data refer to the years 2003-2007, with the exception of Algeria, Egypt, Libya, Morocco, Tunisia, Kuwait, and Iraq whose most updated data available refer to 1998-2002.

[3] The data on water withdrawals by sector for the MENA sub-regional aggregations showed in this section refer to the year 2003 (FAO AQUASTAT 2012).

85% of total water use in Egypt, Morocco, Oman, Saudi Arabia, Yemen, Iran and Syria; and it is over 70% in Libya, Tunisia, United Arab Emirates, Iraq and Turkey (FAO AQUASTAT 2012).

Figure 2.7 Water withdrawals by sector as a percentage of total water withdrawals in the MENA countries [4]



Source: Elaboration based on FAO AQUASTAT 2012

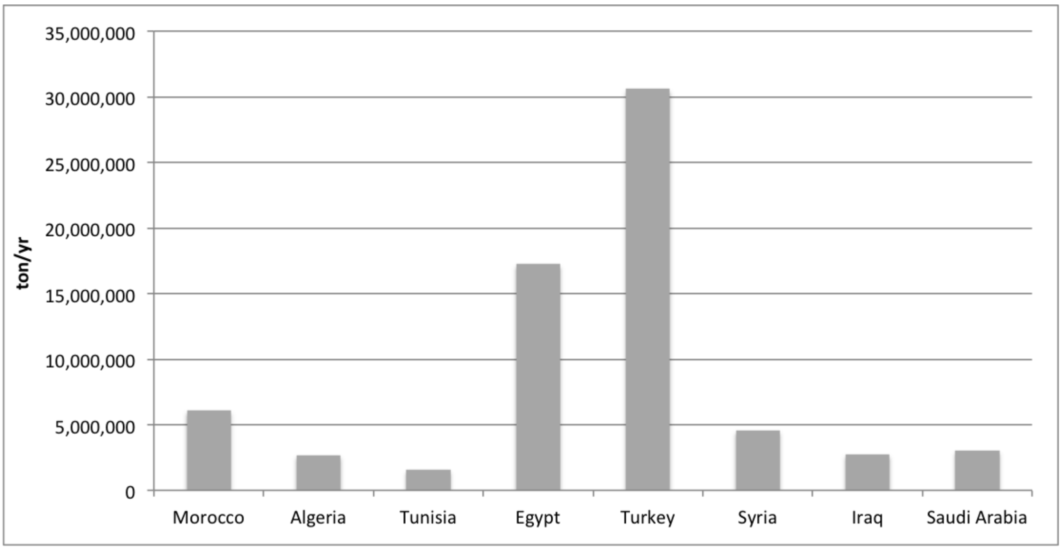
Much of the water withdrawn by the agricultural sector is used to irrigate cereals despite the return generated per cubic meter being a tenth of what would be achieved by growing higher-value crops, such as vegetables (World Bank 2008a). The largest producers of cereal in the region are Turkey and Egypt. Other cereal-producing countries are also Morocco, Algeria and Tunisia in North Africa; and Syria, Saudi Arabia, and Iraq in the Near East (Figure 2.8). Over the past 25 years, all these countries have increased their production of cereals, with the exception of Saudi Arabia (-36% from 1986 to 2010).

[4] All data refer to the years 2003-2007, with the exception of Algeria, Egypt, Libya, Morocco, Tunisia, Kuwait, and Iraq whose most updated data available refer to 1998-2002.

In 2007, Saudi Arabia started a phase of removing subsidies on wheat production, after almost three decades of both direct and indirect support to farmers [5]. In the 1980s and early 1990s, Saudi Arabia was the world's 6th largest exporter of wheat. Subsidised agricultural schemes have proved, however, to be not only "economically unfeasible" but also "ecologically unsustainable" (Woertz 2013: 25). In the "unnatural endeavour to make the desert bloom", about 300 billion m^3 of mostly non-renewable water resources were consumed (Elhadj 2004: 35).

Over the period considered (1986-2010), Egypt's cereal production more than doubled. This increase is the largest in the region (Table 2.7). It is noteworthy to say that Egypt's cereal production completely relies on irrigation since, as it will be shown in Chapter 5 that, the country virtually has no soil water.

Figure 2.8 Cereal production (ton/year) in the major producing countries in the MENA (average, 1986-2010)



Source: Elaboration based on FAOSTAT 2013

[5] Subsidies to wheat will be completely removed by 2016 (Woertz 2013; 2011).

Table 2.7 Cereal production in the major producing countries in the MENA (1986, 1998, 2010)

	1986 [Tonnes]	**1998** [Tonnes]	**2010** [Tonnes]	**Variation [%]**
Algeria	2,403,612	3,025,855	4,002,320	+67%
Egypt	8,754,000	17,964,394	19,464,743	+122%
Iraq	2,280,630	2,431,550	4,362,383	+91%
Morocco	7,824,550	6,629,487	7,834,390	0%
Saudi Arabia	2,460,924	2,201,566	1,565,155	-36%
Syria	3,166,999	5,270,365	3,900,866	+23%
Tunisia	782,000	1,697,820	1,109,471	+42%
Turkey	29,358,150	33,186,972	32,764,875	+12%
Yemen	700,358	832,987	1,012,945	+45%

Source: Elaboration based on FAOSTAT 2013

In 2007-2008, the agricultural sector generated 7.3% of the region's GDP and employed 23% of total labour (World Bank 2012a). The agricultural sector attracts very high levels of state support in the region, mainly in the form of trade protection, domestic price support, subsidised credit and energy subsidies. These policies distort cropping choices, benefit large-scale farming systems the most, and encourage uneconomical water use (World Bank 2008a).

As reported by the World Bank (2007), irrigation networks in the MENA occupy a total area that is equal to that of the United States. Several areas are over-equipped with irrigation networks, given the amount of water available. Irrigation infrastructures have expanded massively since 1970, in particular in the United Arab Emirates (1.234% increase), Tunisia (338%), and Saudi Arabia (374%). The increase in irrigated area exceeds 100% in Syria (181%), Oman (150%), Libya (169%), Iraq (138%), Jordan (114%), and Algeria (101%).

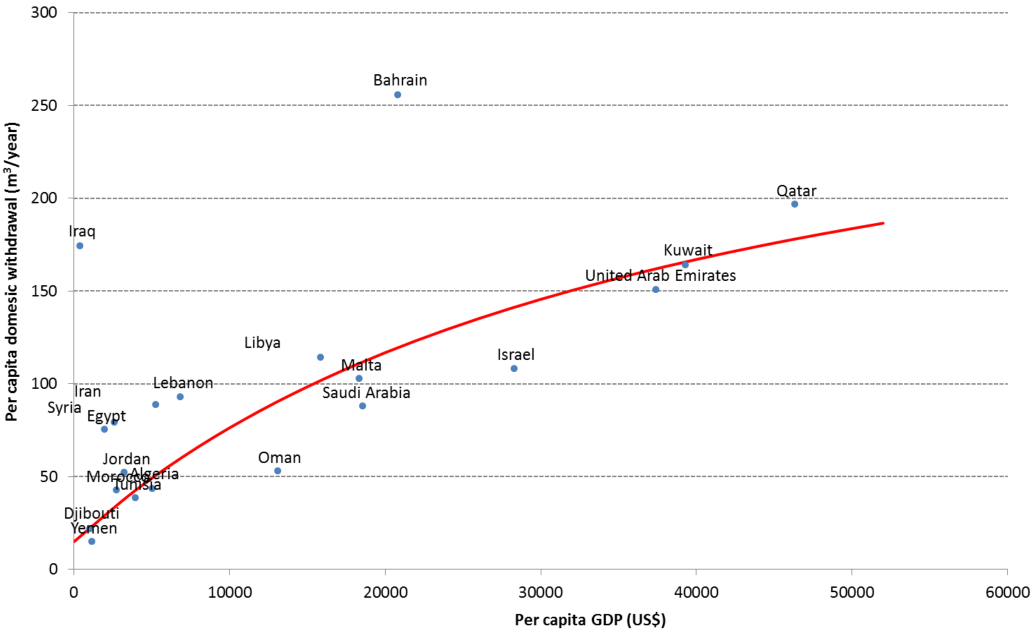
Despite the extreme water scarcity, average water use efficiency in agriculture is very low compared to other areas with similar climate conditions. Average water use efficiency in irrigation stands at 50-60% in the region, as against the best-practice examples of above 80% in Australia and the United States (World Bank

2011). Surface irrigation, which is the cheapest but least efficient method, is the most widely used in the region. There are important exceptions that include Saudi Arabia (Mirata and Emtairah 2010) and Israel (Gilmont 2014a, 2014b). Improved irrigation efficiency could be achieved by "making the right decisions" on crop type, irrigation scheduling and methods, such as the improved management of the soil and root-zone moisture (Mirata and Emtairah 2010: 61). The importance of deploying skilled labour to attain high irrigation efficiency in the region has been highlighted (Al-Hamdy *et al.* 2011).

Water consumption by households and industry in the region is relatively small in most of the region's economies compared with allocations to irrigated agriculture despite the poor returns to water in irrigated farming (Richards and Waterbury 2008). The economies of the Jordan Basin are exceptions. In Israel, Jordan and the Occupied Territories the natural blue water devoted to domestic supplies is converging on that devoted to irrigation (Gilmont 2014b). On a sub-regional level, industrial consumption stands at 6% in North Africa, 3% in the Arabian Peninsula, 1% in Iran and 12% in the Near East, as against a global average of 19%. Municipal water use is 11% in the Arabian Peninsula, 7% in Iran, 11% in the Near East (FAO AQUASTAT 2012), but there are considerable variations between countries, as shown in Figure 2.7 and Table 2.8. Municipal water demand is generally a function of population and income, as increasing prosperity generally triggers an increase in domestic water consumption per capita (Immerzeel *et al.* 2011).

Figure 2.9 illustrates this relationship for some of the MENA political economies. Water withdrawals (total volumes, volumes per capita and volumes by sector) and water withdrawal as a percentage of total water withdrawals by sector are shown, respectively, in Table 2.8 and Table 2.9.

Figure 2.9 Relationship between domestic water withdrawal per capita and GDP



Source: Immerzeel et al. (2011:43)

Table 2.8 Water withdrawals in the MENA countries: total volumes, volumes per capita and volumes by sector [6]

	Agriculture [10^9 m³/yr]	**Industry** [10^9 m³/yr]	**Household** [10^9 m³/yr]	**Total withdrawals** [10^9 m³/yr]	**Total withdrawals per capita** [m³/yr]
Algeria	3.94	0.9509	1.581	6.161	195.9
Egypt	59	4	5.3	68.3	973.3
Libya	3.584	0.132	0.61	4.326	796.1
Morocco	11.01	0.4766	1.628	12.61	428.1
Tunisia	2.165	0.11	0.365	2.85	295.8
Bahrain	0.1592	0.0203	0.1779	0.3574	386
Kuwait	0.4919	0.0233	0.4483	0.9132	441.2
Oman	1.168	0.019	0.134	1.321	515.8
Qatar	0.262	0.008	0.174	0.444	376.9

[6] All data refer to the years 2003-2007, with the exception of Algeria, Egypt, Libya, Morocco, Tunisia, Kuwait, and Iraq whose most updated data available refer to 1998-2002.

Saudi Arabia	20.83	0.71	2.13	23.67	928.1
UAE	3.312	0.069	0.617	3.998	739.5
Yemen	3.235	0.065	0.265	3.565	162.4
Iran	86	1.1	6.2	93.3	1306
Iraq	52	9.7	4.3	66	2616
Israel	1.129	0.113	0.712	1.954	282.4
Jordan	0.6112	0.0384	0.2913	0.9409	166
Lebanon	0.78	0.15	0.38	1.31	316.8
OPT	0.189	0.029	0.2	0.418	112.1
Syria	14.67	0.6154	1.475	16.76	867.4
Turkey	29.6	4.3	6.2	40.1	572.9

Source: Elaboration based on FAO AQUASTAT 2012

Table 2.9 Water withdrawals by sector as a percentage of total water withdrawals[7]

	Agricultur e [%]	**Industry** [%]	**Household** [%]
Algeria	64	14	23
Egypt	86	6	8
Libya	83	3	14
Morocco	87	3	10
Tunisia	76	4	13
Bahrain	45	6	50
Kuwait	54	2	44
Oman	88	1	10
Qatar	59	2	39
Saudi Arabia	88	3	9
UAE	83	2	15
Yemen	91	2	7
Iran	92	1	7
Iraq	79	15	7
Israel	58	6	36
Jordan	65	4	31
Lebanon	60	11	29
OPT	45	7	48
Syria	88	4	9
Turkey	74	11	15

Source: Elaboration based on FAO AQUASTAT 2012

[7] All data refer to the years 2003-2007, with the exception of Algeria, Egypt, Libya, Morocco, Tunisia, Kuwait, and Iraq whose most updated data available refer to 1998-2002.

2.3.3 Water policy

The previous sections have highlighted the MENA water problems in relation not only to the region's limited water supply but also to the way water resources are allocated and managed. This section is concerned with water policy and presents the different approaches that have characterised water resources development in the region since pre-modern times.

As suggested in a World Bank study (2007), water policy in the MENA region has basically undergone three phases. The first phase evolved over millennia and was characterised by the effort of the MENA societies to adapt to the scarcity and variability of water resources over time and space. This phase of water policy is associated with the development of institutions and hydraulic structures that enabled the MENA societies to thrive. According to Allan (2003), water use was generally limited in 'pre-modern' times because both the level of technical advancement and the organisational capacity to capture water resources were very low.

A major shift in the approach to water resources occurred in the 20^{th} century when, as a result of the advancement of the economies and population growth, the public sector embarked upon huge investment programmes aimed at augmenting water supply and expanding services (World Bank 2007). This phase of water resources development has been conceptualised by Allan (2003) as a paradigm of 'industrial modernity'. This paradigm was inspired by the idea that nature can be controlled by means of large-scale hydraulic and other infrastructures (Reisner 1993; Allan 2001, 2003d; Turton and Meisner 2002, Swyngedouw 2004; Molle *et al.* 2009). The 'hydraulic mission' of this phase involved central authorities securing water supplies through the development of dams, reservoirs, irrigation schemes and groundwater extraction projects (Allan 2001, 2003d; Molle *et al.* 2009). The extensive and intensive water capture is generally aimed at increasing irrigation capacity, preventing disasters from flooding, and increasing hydropower capacity (Molle *et al.* 2009).

In the industrialising global North this approach dominated water resource development policy-making until the 1970s, when green priorities and consideration for the environment gained a foothold and began to be widely adopted (Allan 2001). Such changes led to the transition to a phase of 'post-modernity' or 'reflexive late modernity'. This third phase witnessed a reduction of water use in the agricultural sector in a number of semi-arid industrialised and diverse economies, such as Australia, Arizona and California (Allan 2003d). In the MENA region, the reflexive process is only at a very preliminary stage (Allan 2001). As suggested by Allan (1999c; 2001), this is a phase of 'mutual knowledge' (Giddens 1984).

This concept from social theory can be usefully deployed to describe the process which local politicians and societies encounter 'new knowledge' as recommended by outside professionals and scientists which challenges the traditional knowledge and system of belief. In this phase, the ideas introduced by alien scientists are understood and accepted – thus becoming 'mutual knowledge' – , and adopted by a small professional elite of the population. Although this phase witnesses a preliminary understanding of 'new knowledge', this does not mean that water policy can easily be reformed. Water policy is "made in response to discursive political processes" (Allan and Olmsted 2003: 73). Transformation of water policy is subject to the adoption and incorporation of 'new knowledge' into policy by governments and policy makers (Allan 1999c).

In the diverse and industrialised global North, the introduction of 'new water knowledge' and the transition to 'late modernity' is always a long and politically stressful process; in the MENA region this process could take longer than in similar semi-arid and water scarce regions as water policy is informed by deeply entrenched path dependent knowledge and enduring perceptions that are difficult to challenge (Allan 1999c; 2001; 2003). The capacity of numerous rentier economies in the region to ignore economic and environmental constraints does not help.

Until 1986 water policy in all the MENA was driven by the perception that the augmentation of water was the solution to the problem of rising demands for agricultural, industrial and domestic water. The only political economy that has adopted the 'new water knowledge' and embarked upon water reforms is Israel (Allan 1996b). Some progress towards this approach to water resource allocation and management has been witnessed in three other MENA countries − Jordan, Tunisia and Morocco (Allan 2001). However, progress has been sluggish and has not led to the expected improvements in water allocating and managing outcomes that reflect underlying water resource and economic fundamentals. Water is still allocated to low-value uses and water resource management is a serious problem in many countries (World Bank 2007). As Allan put it (2001: 37) the MENA region is a "risk society in waiting" which "has the major risk of water shortages hanging over it but (...) does not yet have the will to interrogate the problem". These issues will be explored in more detail in Section 2.4.

2.4 Water 'solutions' and perceptions

This section is concerned with the way the MENA region has addressed its water-related problems over the past few decades, and the perceptions that inform water policy. The concept of virtual water and its relevance for the MENA region will be discussed. The analysis will show that water policy in the MENA region is fundamentally driven by partially informed and uninformed perceptions that are politically hazardous that hinder the adoption of sound reforms in the water sector.

2.4.1 Virtual water: an *invisible* solution to the MENA water deficit

The MENA is the first region in the world to run out of water (Allan 1994), although this important resource and economic fact has been strategically de-emphasised by local governments and policy-makers (Allan 1997b; 2001). The region as a whole has been water insecure since the 1970s but some economies in the region began to be water insecure in the 1950s and 1960s (Allan 2001; 2002). The main reason for such insecurity is that water demands for food production far exceed local supplies. Not only is the MENA the first region in the world to run out of water but also the first region that has been able to cope with water scarcity without adopting economically or environmentally inspired water resource management policies (Allan 2001).

The market-mediated mechanism through which the MENA political economies have managed to meet the water needs of their populations over the past few decades was identified and conceptualised by Allan (1993) as virtual water 'trade'. The term *virtual water* refers to the amount of water used to produce a good or a service. Accordingly, virtual water *'trade'* is the volume of water 'embedded' in internationally traded commodities, which reflect a virtual 'transfer' of water to the importing countries. Virtual water 'flows' associated with trade can be estimated either as the volumes of water actually used by the country exporting a good, or the water which would have been needed to produce that same good in the importing country (Zimmer and Renault 2003). Whether virtual water 'trade' generates water 'savings' at the national or global level is a highly debated issue. The concept of water 'savings' was presented by Chapagain and Hoekstra (2004). A nation can save domestic water by importing water-intensive commodities rather than producing it locally and loose domestic water by exporting them to other countries. These issues will be explored in more detail in the next Chapter.

Agricultural production is the dominant consumptive use of water resources globally (Shiklomanov 1997; Oki and Kanae 2004; Hoekstra and Chapagain 2008; UNESCO 2009). The level of food imports can thus be considered as the major indicator of the scale of the water stress of an economy. The reliance on imports to secure local needs of food has been made increasingly attractive by a long-run downward trend in prices of food commodities (Rosegrant *et al.* 2001). The MENA is the most food import dependent region in the world (Wright and Cafiero 2011; Breisinger *et al.* 2010). Over 50% of the food consumed by MENA populations is imported (World Bank 2008b). Basic grains, which are generally at the core of national calls for food self-sufficiency (Lofgren and Richards 2003), are a major import in most of the MENA countries (Minot *et al.* 2010).

The political siren song of food self-sufficiency in the region is, however, still very strong (Richards and Waterbury 2008). The perceived risk of vulnerability on such sensitive issue as *food* has, in some cases, "motivated desires for self-sufficiency", such as in Saudi Arabia and the UAE (Woertz 2013). The costs of food policies aimed at self-sufficiency in the region have been shown to have significant impacts on the sustainability of water resources in the region, driving a doubling of present blue water demands (Larson 2013a; 2013b). The region's countries that are most vulnerable in terms of food security are Syria, Iran, Morocco and Tunisia, not only due to high food imports relative to export earnings but also to their populations' dependence on agricultural livelihoods (Dasgupta *et al.* 2003).

MENA agricultural imports have ranged between US$ 16-20 billion over the past 20 years (Dasgupta *et al.* 2004). The EU is the main trading partner of most of the countries in the region. The MENA countries, especially the non-oil-exporting MENA economies, have levels of trade protection that are far higher than in most developing countries. The agricultural commodities which are most protected are wheat, sugar, dairy and livestock products (Minot *et al.* 2010). Non-tariff trade barriers are also in place in almost all the region's countries (Dasgupta *et al.* 2004; Richter 2012).

Allan (2001) argued that the 'import' of water 'embedded' in food commodities has enabled the MENA countries to meet the demographically driven increase in the demand for water-intensive commodities, such as grains, since the 1970s. The reliance on food imports was made easier by the low global prices for staple food commodities in the beginning of the1970s. They were at an historic low and - after the oil related food commodity price spikes of 1973 and 1979 - continued to decline. What drove prices down was mainly related to technological advancement, and the production and export subsidies of food commodities in the U.S. and Europe (Allan 2002a; 2002b). The 'transfer' of virtual water to the region's water deficit economies resulting from trade exceeds the annual flow of the Nile River (Allan 1997b).

The level of per capita cereal consumption increased considerably during the 1970s, both for direct and indirect consumption, associated with the increased consumption of livestock products (Dyson 2001). Rising oil revenues enabled the political economies of the Middle East to increase the level of cereal imports up to a volume accounting for one third of its total cereal demand (Dyson 1996). The reliance on food imports thus proved to be a painless political economy process for the MENA countries.

Food and animal products currently represent about 75% of the region's total imports; cereals account for 25-40% of agricultural imports in all the MENA countries, with the exception of Lebanon (Minot *et al.* 2010). Arab countries are the largest net importers of cereals in the world (World Bank 2009a). Wheat imports are the main 'vehicle' of virtual water. It has been shipped at half its production cost for decades (Hakimian 2003). It accounts for half of total cereal imports in the MENA region (Minot *et al.* 2010). The MENA countries have imported 40 million tonnes of cereals annually since the end of the 1980s (Allan 1999a, 1999b). They accounted for 25% of global grain imports in 1997 (Brown and Halweil 1998). Given the high dependence on food imports, the region is clearly vulnerable to increases in food prices, such as that in 2007-08 (Von Braun 2008), and to volatile international prices of grains, particularly wheat (World Bank 2012b).

The political economy of water resources in the MENA region is dominated by the region's engagement in the political economy of the global food trade. The MENA economies access the current surplus water in the global hydrological system (Allan 2001; 2002a; 2002b; 2002c). Economic systems thus provide the MENA with the solution to both water and food deficit problems. In this sense, the diversification of the economy and the capacity to engage in trade are major determinants of water and food security. In other words diverse and strong economies can easily overcome water resource constraints: water poverty does not determine poverty, whereas poverty does determine water poverty (Allan 2012).

The availability of water in the global system determines the water and food security of the MENA water-deficit countries. The water used in global food production is mainly soil water – also referred to as *green* water – located in humid and temperate countries. These water resources meet the water deficits of the MENA economies Soil water represents over 80% of the virtual water 'embedded' in global food exports (Fader *et al.* 2011; Hoekstra 2011), as virtual water generally 'moves' from soil water rich countries to arid and semi-arid countries, which are relatively more dependent on surface and groundwater sources (Yang *et al.* 2006; Aldaya *et al.* 2010a; Fader *et al.* 2011; Mekonnen and Hoekstra 2011a).

Despite accounting for 84% of global crop production (Fader *et al.* 2011), *green* water has been ignored by conventional water scarcity assessments until very recently. An increasing number of analysts have highlighted the importance of integrating soil water in water resource assessments over the past few years (Falkenmark and Rockström 2006; Molden 2007; Hoff 2009; Aldaya *et al.* 2010a; Hoff *et al.* 2010; Rockström *et al.* 2010; Allan 2011). In the MENA region, this source of water is totally invisible. It has never been taken into account in the national water budgets of the MENA political economies, although it provides resources for the crop and livestock outputs of the widespread dryland winter farming and grazing of the region (Chatterton and Chatterton 1996; Allan 2001).

Besides providing the region with water and food security, virtual water 'trade' has also had another important impact on the political economies of the MENA region. As shown by Allan (*ibid.*), 'importing' virtual water is an economically efficient and, more importantly, a politically and socially silent and acceptable solution to water resource and food deficits. By relying on virtual water 'trade', the MENA political leaders have been able to cope with progressive and occasionally local agricultural water deficit, while avoiding politically hazardous reforms of the water sector. The role that virtual water 'trade' plays in bringing water and food security to MENA economies has been kept silent for many decades by the dominant local narrative that *no* water shortage exists yet. As Allan put it (2002a: 12), politicians "happily look outside the watershed" as they have access to the 'problemshed' of global trade. These issues are explained in more detail in the following section.

2.4.2 Water perceptions and the 'sanctioned discourse'

The previous sections have argued that water and food self-sufficiency in the MENA region is unattainable given the local water resource endowments and the trends in demand. International economic systems provide water and food security to the region's countries through virtual water 'trade'. Alien professional and scientists consider such insecurity neither special nor determining of economic security. They point out, on the contrary, that resource poverty does *not* determine poverty (Karshenas 1994; Turton and Ohlsson 1999; Allan 2012). This is the case of the highly diversified economy of Singapore, for instance, which is water secure despite it has only 5% of the water needed (Allan 2012).

These ideas are especially relevant to the MENA region, but they cannot be conceded because of the impossibly high political price politicians would pay if they were publicly debated (Allan 2001). The concept of water security that dominates the discourse is that the amount of freshwater available locally is sufficient and that this is proved by the absence of municipal water shortages across the region's countries (Allan 2002a; 2002b). What is obscured in official water discourse in the region is that municipal – as well as industrial – water consumption accounts for a tiny share of the total needed by an individual and an economy, roughly 10%. Almost all countries in the world can easily meet municipal water requirements via conventional or non-conventional water sources, whereas the same is not true for agricultural water needs (Allan 2012).

As a result of the selective use of information regarding the national water insecurity, water perceptions in the MENA are shaped by distorting beliefs that have led to a striking lack of awareness of the underlying water resource and political economy fundamentals. Water is perceived and treated as a social resource rather than an environmental and economic one. This perception is based on 'old knowledge' that is politically hazardous to contradict (Allan 19991; 1999b; 1999c; 2001). Water users in the MENA region are afflicted by a deficit of accurate knowledge and information on water because it is politics that dominate the discourse. Water resources in the MENA region are culturally defined and politically managed. As a result of the manipulation of the awareness of risk by policy officials advocating politically safe decisions, and of socio-political circumstances, the peoples of the MENA region do not perceive themselves to be at risk with respect to water deficits. The disjuncture between what is known and the impact of the water challenge in the region is extreme (Allan 2001).

In these circumstances, implementing water policy reforms is “economically irrational and politically suicidal” (Zeitoun *et al.* 2011: 2). The MENA water users and politicians are locked in a ‘sanctioned discourse’ (Tripp 1996 in Allan 2000), i.e. “a normative vision in which the thought process of an analyst or political actor is locked (...) that determines the hypotheses we can put out and the questions we can ask” (Tripp 1997 in Trottier 1999: 164). In other words, the sanctioned discourse is the discourse that is permissible in contexts where traditional knowledge and beliefs are strong and deep-rooted. In the MENA region, the sanctioned discourse fundamentally determines the extent to which sound water policy reforms can be proposed and achieved. The sanctioned discourse is particularly strong in the MENA region as the region is characterised by ‘strong societies and weak states’ (Migdal 1988 in Allan 2000). This fact has serious consequences when ‘new knowledge’ challenge deeply entrenched belief systems.

Furthermore, public officials promoting and resisting water policy in the MENA region can dispute whether there is a water deficit at all in the region. Unfortunately there is a significant lack of precision in measuring and reporting water availability and use at both the national and regional level. There is also disagreement on whether water-self-sufficiency, that is mainly the capacity of raising food to meet the national demand, should be regarded as a strategic goal, as “no community apparently enjoys the prospect of being non-water-self-sufficient” (Allan 2000: 120). The reluctance of national governments to make the problem public is in fact a consequence of their deep concern regarding the public’s perception of a nation’s dependence on international trade for such a significant portion of its food supply. In the 1970s, the concern generated by the decline in the region's food self-sufficiency capacity provided the rationale for attempting to expand local food production through massive investment and ambitious agricultural policies. These policies included the expansion of irrigated land, the increase in subsidies to farmers, and the overexploitation of water resources (Allan 2001). Notwithstanding, food imports have remained the most substantial component of the MENA total food supply (Allan 1995).

Finally, it has been highlighted that, by virtue of the 'trade' in virtual water for the past half century, those responsible for allocating water resources in the MENA region have been able to avoid water-related political crises and they have maintained the *status quo* with respect to water resource allocation and management Economically and environmentally sound water reforms, which would require changes and water re-allocation policies, have never taken place in the region – with the exception of Israel (Gilmont 2014a, 2014b). It is likely that adjustments in the public perception of the value of water and water policy require a transitional period of some decades. Although sluggish water reforms in water-short countries are not unique to the MENA region but, given the scale of the challenge in the region, the cost of inaction is likely to be higher there than elsewhere (World Bank 2007). It is, therefore, of the utmost importance that progress and awareness be accelerated.

2.5 Conclusions

This chapter has presented and analysed the main environmental, economic and political issues that make the MENA water question particularly urgent. It has also identified the nature of the region's political economies and how they have addressed water deficits and highlighted what hinders the promotion of sound water reforms in the water sector. The contexts and ideas presented in the chapter will be essential in framing the analytical chapters. These contexts have led to the establishment of the main research questions and hypotheses of the study. The main gaps in the existing literature on the MENA region have also been identified. The following chapter presents the theoretical framework and concepts informing the research on water resource and food security in the MENA region.

3. Theoretical framework: redefining the contours of water security research through a multidisciplinary approach

3.1 Introduction

The aim of this chapter is to detail the theoretical and analytical frameworks deployed throughout the study on food-water security in the MENA region. *Food-water* is the water needed to produce food and accounts for 90% of the water needed by an individual or a society, as opposed to *non-food water*, that is the water used by households and industry (Rokstrom *et al.* 2006). The chapter outlines and brings together the theory and the concepts that will be used to address the main research question which guides this study, as initially identified in Chapter 1: **How has the MENA region coped with water scarcity?** And more specifically: **How have these MENA economies achieved their water and food security?** The previous chapter highlighted the limitations of previous analysis of water and food security in the MENA region. The present study develops an original and multi-disciplinary theoretical and analytical framework in order to grasp the forces and dynamics that underpin water and food security in the region. It will be shown that these forces lie *beyond* the water sectors of the MENA national economies.

The underpinning assumption of the study is that the market-mediated mechanism of virtual water 'trade' has been able to mitigate regional water deficits in the broader political economy and to provide water security for water-scarce MENA economies. This virtual water 'trade' remedy has been shown to be economically feasible, as a consequence of the low food prices in the international market. It has also been politically silent, as it has enabled public officials to de-emphasise or even neglect the urgency and the scope of the domestic deficit in the MENA. Such *politics* determine the extent to which the water issue is constructed, recognised and finally addressed.

The main purpose of the study is to investigate critically and extensively how the MENA economies have coped with water scarcity by shedding light on the role that virtual water 'trade' has played in underpinning food-water security in the region over the past 25 years. The theoretical and analytical approach deployed will reveal that economic diversification and social 'adaptiveness' are the locus of water and food security in the arid and semi-arid MENA political economies. The research will also supplement and enrich the existing literature on water security in the region.

By virtue of the broad and cross-sectoral nature of the subject, the theoretical framework informing the study has been developed via a wide range of theories and concepts. The concept of Virtual Water, identified by Allan in the early 1990s, is the *fil rouge* ("unifying thread") that runs through the whole research, as it effectively captures the relationship between water resources security and food security. The economic rationale behind the virtual water concept is consistent with economic trade theory and the Heckscher-Ohlin theorem.

Concurrently, the study employs the theory of Social Adaptive Capacity conceptualised by Ohlsson (1998; 1999). The insights provided by this theory will be applied to the analysis of differential capacities to 'adjust' (water-related) first-order scarcities by means of second-order resources (institutional capacity, financial resources, human resources, etc.). Building on this idea, the study will show that socio-economic development is normally a prerequisite to 'accessing' virtual water in the global system (Allan 2006).

This chapter presents the theoretical underpinnings of the study. It is organised as follows. The next section outlines the basic concepts informing the research and employed throughout in order to investigate the MENA region's water and food security. The third section is concerned with the relevant elements of the Virtual Water concept and identifies their relevance to the study. The fourth and fifth section presents some complementary theory and concepts that will guide the analysis. The sixth part outlines the research questions, sub-questions and the hypotheses of the study. Some conclusions are drawn in the final section.

3.2 Basic concepts informing the study

This section presents the basic concepts informing the study – namely, food-water and non-food water – and also distinguishes between green and blue water resources. These concepts will be deployed throughout the study in order to answer the research questions.

3.2.1 Food-water and non-food water

The study deploys the concepts of *food-water* - the water deployed for producing food commodities, and *non-food* water - the water consumed by industry and households - in order to capture the very close relationship between water security and food security. This useful conceptualisation has been recently introduced by Allan (2013a) to draw attention on the global significance of water in food supply chains, and replaces the previous differentiation between 'big water' and 'small water' (Allan 2005; 2011). The focus of the analysis is on *food-water* as it accounts for the overwhelming majority of the water used by individuals - about 90%. Food water can be either soil water - *green* water, or surface and groundwater - *blue* water. Most of the world's economies are food-water insecure and meet their food-water needs through imports. The MENA economies are all in this category. Farmers are the strategic managers of food-water in food supply chains (Allan 2012; 2013a).

Non-food water accounts instead for a tiny percentage of an individual's water needs (10%) and can only by sourced from rivers, lakes or aquifers. Non-food water will *not* be considered here as only a very few countries in the world cannot secure the domestic freshwater needs of their populations. The case of Singapore and Israel, for instance, demonstrate that it is possible to meet non-food water needs despite extreme water poverty by means of accumulating financial capital and enhancing human capital, as well as by deploying engineering, commercial and regulatory capacities. As Allan pointed out (2011, 2012), societies are non-food water insecure not because of water poverty, but due to a lack of diversified and adaptive economies.

The term food-water will also be used for the purpose of drawing attention to political economy processes that underpin water and food security in the MENA countries. Food-water security and non-food security are only partially dependent on local availability of water resources. Water endowments are generally inadequate to meet local food-water requirements, especially in countries where rising populations and incomes are driving a very rapid increase in water demands. Food-water security and non food-water security are more related to the effectiveness of their allocation and management.

This study argues that in the MENA region, as well as in the other world's water-deficit economies, water and food security have been provided by international trade in food over the past decades. International food trade is in practice an implicit exchange of the water 'embedded' − as a factor of production − in the traded commodities. This hypothesis will be tested in the analytical Chapter 6.

3.2.2 Green and blue water resources

In investigating the MENA water and food security, the present study distinguishes between the two sources of food-water, namely blue and green water resources. Food is produced through photosynthesis, the process by which plants make carbohydrates from carbon dioxide and water, using the energy captured from sunlight. Water is absorbed by the roots from the store of infiltrated rain in the soil and becomes soil moisture. Soil water has a productive role in the biosphere as transpiration, and a non-productive role as direct evaporation from soil. This water has been referred to as *green water* (Falkenmark 1995) as opposed to *blue water*, which is the water stored in surface and groundwater bodies (Falkenmark and Rockström 2004). Green and blue water are both involved in food production. The former sustains global rainfed agriculture as well as ecosystems and ecosystem services; the latter can be diverted to irrigate crops. Good yields are achieved when plant roots gain access to an amount of green water that is sufficient for efficient photosynthesis. When green water resources are insufficient, blue water resources may be added as supplemental irrigation. Farmers, however, will have to compete for blue water as it performs other fundamental societal functions, such as meeting domestic water demand, industrial use and energy production.

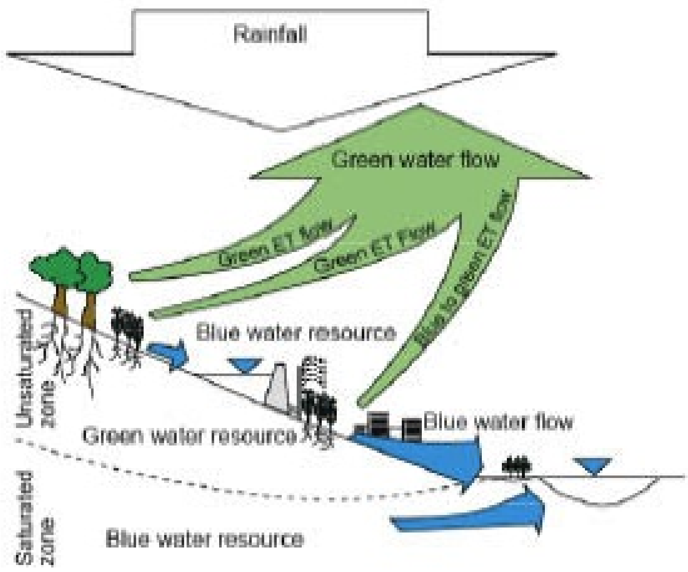
Green water has been defined in many ways. Falkenmark (1995) defined it as the total volume of water evaporated from soil moisture. Rockström (1997 in Ringersma *et al.* 2003) defined it as the water that originates mainly from rainfall but, also from run-off and overland flow infiltrating the root zone, as well as irrigation water. According to Saveniie (1999), green water equals transpiration by plants of water derived directly from rainfall stored in the soil. Ringersma *et al.* (2003) proposed to define it simply as the water resource held in the soil that is available to support plant growth. Falkenmark and Rockström (2006: 129) defined green water as a *flow* made up of the amount of water that is consumed as "transpiration flow and released as vapour from the plant canopy" together with "non-productive evaporative losses of water (from soil, ponded water and intercepted water from foliage surface)". The interplay of green and blue water resources generates flows in the hydrological cycle (Karlberg *et al.* 2009).

Falkenmark and Lannerstad (2005) described how blue water flow transforms into green water flow as a result of evaporation from irrigated fields, wetlands and evaporating surfaces. This definition, however, makes it difficult to differentiate the part of the evaporative demand of a crop met by direct rainfall and the part met by irrigation water supply replenishing the deficit soil moisture. Doll (2002) defined green water as the evaporation from rainfed land. This definition was used by Chapagain *et al.* (2006) to compute the green water footprints related to cotton consumption.

Hoekstra *et al.* (2011: 30) refer to green water as "the precipitation on land that does not run off or recharge groundwater but that is stored in the soil or temporarily stays on top of the soil or vegetation. Eventually, this part of precipitation evaporated or transpired through plants". Green water can be made productive for crop growth (but not all green water can be taken up by crops, because there will always be evaporation from the soil and because not all periods of the year or areas are suitable for crop growth). Gerten *et al.* (2011) defined it as the water evapotranspired on cropland and grazing land in a country, equalling total evapotranspiration in rainfed areas and equalling total evapotranspiration minus evapotranspiration of blue irrigation water in irrigated areas.

Figure 3.1 illustrates the cycle of green and blue water resources.

Figure 3.1 Green and blue water resources



Source: Falkenmark and Rockström (2006: 129)

Evapotranspiration can be measured either on field or estimated through models using climatic, soil properties and crop water use data. Models of evapotranspiration and crop growth include the EPIC model (Williams *et al.* 1989); the CROPWAT model developed by FAO, based on Allen *et al.* (1998); and AQUACROP that estimates evapotranspiration under water-stress conditions

(FAO 2010). Gerten *et al.* (2011) estimates of green water through the LPJmL model are extensively addressed in the Methodology chapter, as this is the source of data deployed in the study to assess the MENA water availability for food production (Chapter 6).

Green water availability is highly correlated to a country's precipitation pattern, soil profile and climatic conditions. It is the majority water in humid temperate and humid tropical temperate regions, whereas it is relatively scarcer in arid and semi-arid environments. Originating from rainfall, green water is commonly regarded as "a 'free good' in terms of supply" (Yang and Zehnder 2008: 9). It is invisible to users as it is accessible only to plants and cannot be directly manipulated by human management. Blue water availability is not rain-dependent as much as green water but it is dramatically limited in supply (Zaidi and Rashid 2008).

Water resource planning and management, as well as water knowledge, have traditionally been focused on blue water (Falkenmark and Rockström 2006). The role that water plays in food production has in fact traditionally been associated with the 'miracle' of irrigation (SIWI, IFRI, IUCN, and IWMI 2005; Aldaya *et al.* 2010a), although rainfed agriculture is the world's predominant agricultural production system (Rosegrant *et al.* 2002; FAO 2011; FAO 2013). In this study it is argued that, when analysing food production, it is essential to include green water, as it represents the most important source of agricultural water globally. Recent estimates are that 84% of the water used in agriculture is green, as well as 94% of the water 'embedded' in internationally traded crops (Fader *et al*. 2011). Global water and food security are, therefore, mainly reliant upon this source of water. Green water also accounts for 74% of the water footprint of humanity in global consumptive water use for agricultural, industrial and domestic purposes (Hoekstra and Mekonnen 2012) [8]. Although green water provides resources for the crop and livestock outputs of the widespread dryland winter farming and grazing, policy-makers in the MENA ignore it (Chatterton and Chatterton 1996;

[8] The "green water footprint" refers to the volume of green water consumption over a certain period and is clearly related to water use in crop production.

Allan 2001). For this reason, a major aim of the present study is to draw attention on this source of water.

The importance of green water for global water and food security as a major source of agricultural water, as well as the need to incorporate it in water scarcity assessments, has been highlighted by an increasing number of studies (Allan 2001; Rockström 2001; Falkenmark and Rockström 2004, 2006; IMWI 2007; Rockström *et al.* 2007; Aldaya *et al.* 2008; Rost *et al.* 2008; Liu *et al.* 2009; Rockström *et al.* 2009; Rost *et al.* 2009; Aldaya *et al.* 2010a, 2010b; Hoff *et al.* 2010; Rockström *et al.* 2010; Allan 2011; Gerten *et al.* 2011; Allan 2013a, 2013b). Drawing on these studies, the present study will provide an assessment of food-water scarcity in the MENA political economies by considering the availability of both green and blue water resources for food production, thus overcoming a major limitation of previous studies.

3.2.2.1 Characteristics and opportunity costs

Green and blue water resources have different characteristics, which lead to different opportunity costs in their use. First, green and blue water differ in terms of volumes. The rain falling over continents accounts for 110,000 km^3 per year on average. Around 35% of this water replenishes blue water sources, that is, aquifers, rivers and lakes, but only 11% can be deployed for agricultural, industrial and domestic purposes. The remaining two-thirds (65%) of water becomes soil moisture, i.e. green water, or returns to the atmosphere evaporating from wet soil and transpiring through plants (SIWI, IFRI, IUCN, and IWMI 2005). Green water is thus a very significant source of water: its volumes are far bigger than those replenishing the world's surface water and aquifers.

Secondly, green and blue water differ in terms of alternative uses. Green water cannot be moved or pumped. It is a local resource that is available only to farmers and ecosystems. Agriculture and ecosystem services are the only two competing uses for green water. Compared to blue water, the opportunity cost of green water use is far lower, as it cannot be reallocated to other uses (Hoekstra and Chapagain

2008; Yang and Zehnder 2008). It has been shown that, as green water use for vegetation growth generally yields lower economic value than crop production, rainfed agriculture is generally efficient in terms of opportunity cost (Yang *et al.* 2006). Blue water, by contrast, is the resource with the highest economic potential. It can perform numerous functions, and its opportunity cost is therefore very much higher than green water. Blue water can fulfil municipal, industrial and service functions – as well as supporting natural vegetation in conjunction with green water. Blue water in irrigated agriculture yields the *lowest* economic value among all other use options (Zehnder *et al.* 2003). From the viewpoint of opportunity costs, 'trading' green water through virtual water 'trade' is overall more efficient than 'trading' blue virtual water (Yang and Zehnder 2008).

This study argues that allocating blue and green water resources informed by an opportunity cost analysis can assist with delivering effective productivity improvements in water resource use based on the competing economic, social and environmental demands. By unlocking the productive potential of green water, blue water demand can be 'freed up' for other purposes for which there is no substitute and that yield higher values than irrigated agriculture. These purposes include domestic and industrial supply, and environmental flow requirements, which are crucial for maintaining river basin health and avoiding traditional environmental and social negative externalities.

Thirdly, as pointed out by Allan (2012: 6), a major difference between green and blue water resources is in their degree of vulnerability to over-allocation. Green water "tends to look after itself" as it cannot be over-allocated. Conversely, blue water resources can be withdrawn beyond natural rates of recharge. "The decision to irrigate always leads to a form of blue water over-allocation".

Finally, green and blue water differ in terms of externalities (or spill-over effects) arising from their use[9]. Green water use in agriculture is associated with relatively few negative environmental externalities (Aldaya *et al.* 2010a). Its impact is far smaller than blue-water based irrigated agricultural systems, which may

[9] An externality is a cost (or benefit) that affects other parties without being reflected in the cost of goods or services involved.

irreversibly impact on natural water bodies (Yang *et al.* 2006)[10]. Irrigation is generally associated with significant negative environmental externalities, such water logging, salinisation, and soil degradation (Zehnder *et al.* 2003). These environmental externalities may result from the depletion of stream flows by crop water use in irrigation systems, additional impacts of storage of stream flow or runoff in dams or reservoirs, groundwater mining, herbicide and inefficient fertiliser application etc. (FAO 2011).

3.2.2.2 Green and blue water for future food production: the need for a paradigm shift

The aim of this section is to call for the promotion of a broadened approach towards water resources, which not only recognises the role played by green water in agriculture globally, but also considers rainfall as the "ultimate source of water" that can be managed (Molden 2007: 3).

According to recent estimates, overall food production (both irrigated and rainfed) consumes 6,800 km^3/year globally. In developing countries, consumptive water use accounts for 4,500 km^3/year, that is, two thirds of global water use in agriculture. In view of future population growth, the foreseeable increase in water requirements in order to produce a balanced diet of 3,000 kcal per capita day will amount approximately to 4,200 km^3/year by 2030 – that is almost a *doubling* of current water use (Falkenmark and Rockström 2006). In 2050, the amount of water needed to eradicate food insecurity will reach up to 5,600 km^3/year – that is almost *three* times as much as present consumptive use of water resources in irrigated agriculture (SIWI, IFRI, IUCN, and IWMI 2005). The challenge is therefore posed onto how to bridge the emerging gap between limited water supply and increasing food demands.

It has been argued that addressing the challenge of the future requires a re-thinking of conventional water-resource planning and management towards a new

[10] The use of both green and blue water in agriculture is, however, associated with a degradation of water quality due to the use of fertilizers and pesticides (Aldaya *et al.* 2010).

"widened green-blue water approach" (Falkenmark and Rockström 2006: 126). Water resources development and perceptions have traditionally been focused on blue water resources, while ignoring the importance of green water (Falkenmark and Rockström 2006; IMWI 2007). Especially since the industrial modernity, extensive and intensive water mobilisation from natural bodies has been conducted through investments in large-scale hydraulic infrastructures (Reisner 1993; Turton and Meisner 2002, Swyngedouw 2004; Molle *et al.* 2009). This *hydraulic mission* embarked upon by public authorities was accompanied by unprecedented ecological impacts, which have been defined as "un-mistakable manifestations that the Anthropocene[11] is a fact" (Savenije *et al.* 2013: 7624). These impacts include degradation of aquatic ecosystems goods and services and costs to the livelihoods relying on them, modification of river flows, disappearing natural lakes, over-abstraction of groundwater, degradation of water quality (Postel 2000; Pearce 2006; Brichieri-Colombi 2009; Molle *et al.* 2010).

Rainfed agriculture is the predominant agricultural production system in the world (FAO 2011). As highlighted by the International Water Management Institute (2010), the contribution of rainfed farming to food production is particularly high in developing countries. The percentage of rainfed agriculture in farmed lands stands respectively at 95% in sub-Saharan Africa; 90% in Latin America; 75% in the Near East and North Africa; 65% in East Asia and 60% in South Asia. Rainfed agriculture accounts for the majority of land areas in a number of Northern and Southern African countries (Gilmont *et al.* 2012).

There is much potential for improving the productivity of rainfed agriculture, not only because green water has been the bigger contributor to food production globally, but also given the current generally low productivity of its use (Hoff *et al*. 2013). Both land and water productivity are generally low in rainfed systems because of the combination of low soil fertility, nutrient depletion, poor soil structure and soil management strategies – which results in high levels of evaporation and runoff – as well as because of inadequate water management

[11] The term *anthropocene* has been first used by Crutzen and Stoermer (2000) to indicate the current geological epoch. The term emphasises the role of humans in geology and ecology.

practices (IWMI 2010; FAO 2011). The maximisation of green water potential in rainfed agriculture goes hand in hand with improvements in soil conditions through integrated land and water management (Falkenmark and Rockström 2006; IMWI 2007). In the poorest countries of the world, only one-fifth of potential productivity in rainfed systems is obtainable, given the lack or limited availability of other agricultural inputs and appropriate management capacity (FAO 2013).

It has been estimated that 75% of the global water requirements for increasing food production could be met by improving the productivity of low yielding agriculture in developing regions to a level of 80% of the productivity of high yielding agriculture (IMWI 2007). Africa has one of the lowest levels of agricultural productivity for unit of water (Vohland and Barry 2009). Green water use is estimated to have an average efficiency of 10% to 30%, i.e. the percentage of green water contributing to productive evapotranspiration (Falkenmark and Rockström 2006). In contrast, some areas in the MENA region have productive efficiencies of green water of over 60% (Rockström *et al.* 2009). Both in Africa and the Middle East, there are significant opportunities to boost agricultural output and water productivity while avoiding irrigation lock-in and risking over-abstraction of environmental water (Gilmont *et al.* 2012). The green water potential has been demonstrated by Zeitoun *et al.* (2008) for the Nile Basin. The green water resources has the potential to help meet the future food needs of the MENA region by increasing yields from green water by two or three times (Molden 2007).

Closing the water gap for feeding future generations will thus fundamentally depend on the extent to which broader approaches to water-resource planning and management will be developed and promoted. These approaches must recognise the role played by green water in sustaining food production globally and its potential for bridging future food-water needs. The challenge is thus not only to achieve a ‘doubly green revolution’ founded on the principles of environmental sustainability (Conway 1997), but also to achieve a *paradigm shift* in the focus of water resources planning and management from runoff to rainwater, thus achieving a "triply green revolution" (Falkenmark and Rockström 2006: 126).

3.2.3 From water scarcity to food-water scarcity

The aim of this section is to define *water scarcity* as used in this study, given the focus of the analysis on food-water resources.

Water scarcity is critical to an array of global challenges that stem from malnutrition, poverty, environmental sustainability, resource management, health and sanitation (Rijsberman 2006). There are several ways of defining water scarcity and there is a growing body of literature focusing on the concept. According to the UN, water scarcity can be defined as "the point at which the aggregate impact of all users impinges on the supply or quality of water under prevailing institutional arrangements to the extent that the demand by all sectors, including the environment, cannot be satisfied fully" (UN World Water Day 2007: 4). As summarised by Rockström *et al.*, "water scarcity is the general collective term when water is scarce for whatever reason" (2009: 3).

Water scarcity can occur at the supply level or be related to the demand for water. Whether supply or demand-induced, water poverty does *not* determine poverty. Poverty occurs when physical water scarcity is combined with poor socio-economic capacity (Allan 2011). The strength and diversification of the economy has an important impact on water management as diversified economies "make it much easier for countries to allocate water according to principles of economic efficiency", as "those who lose water or agricultural livelihoods as a result of reforms can be compensated or can find alternative employment" (World Bank 2007: 98). The extent to which socio-economic development and 'adaptiveness' enable countries to cope with the scarcity of water (or other natural resources) is addressed further in Section 3.5.

Water quality degradation also contributes to water scarcity, and has multiple consequences on human health, the environment, and vulnerable communities.

Urbanisation, the intensive use of fertilizers and pesticides, land degradation, lack of adequate disposals of human waste, as well as climate change are among the factors that affect the biological, chemical and physical characteristics of water (UNEP 2010; UN WWAP 2009). River and groundwater flows should also remain within certain boundaries ('environmental flow requirements') for the sake of blue water-dependent ecosystems and human livelihoods (Hoekstra *et al.* 2011).

Over the past few decades, numerous indicators have been developed to assess water resource scarcity. Rijsberman (2006), and Brown and Matlock (2011) have provided comprehensive reviews of water scarcity indicators, which include:

- The "Falkenmark indicator", defined as the fraction of total runoff available for human use. The index thresholds of 1,700 m^3 and 1,000 m^3 per capita per year indicate, respectively, the thresholds between water stress and water scarcity (Falkenmark 1989);
- The "Basic Human Requirement Index" conceptualised by Gleick (1996), which accounts for the total need of water for meeting all basic human needs, such as drinking, cooking, bathing and sanitation. The index indicates a total of 50 litres per person per day.
- A water scarcity index relating water resource availability and cereal imports was developed by Yang *et al.* (2003). The study identified 5,000 m^3 per capita per year as a threshold of water scarcity, also predicting that countries falling below this threshold lack water resources required for local food production and that, as a result, must import cereal grains in order to compensate for the local water deficit;
- The "Water Resources Vulnerability Index", that indicates the ratio of total annual withdrawals to available water resources, according to which a country is water scarce if annual withdrawals are between 20-40% of annual supply, and severely water scarce if withdrawals exceed 40% (Raskin *et al.* 1997);

- A “simple water scarcity approach” based on simultaneous consideration of both water quantity and water quality, was developed by Zeng *et al.* (2013). Water scarcity is defined as the sum of a blue water scarcity index (ratio of the water withdrawal to freshwater resources in a specific area during a given period of time) and a grey water scarcity index (ratio of grey water footprint to freshwater resources in a specific region in a given period of time).

Water scarcity assessments have generally been focused on freshwater availability, i.e. the *blue* water stored in rivers, lakes, reservoirs and aquifers (among others, Vörösmarty *et al.* 2000; Arnell 2004; Alcamo *et al.* 2007; Islam *et al.* 2007; Hanasaki *et al.* 2013), while neglecting the fundamental role that green water plays in underpinning rainfed crop production and sustaining ecosystems globally. National and international water datasets, such as AQUASTAT, the global water information system, developed by the Land and Water Division of the Food and Agriculture Organisation of the United Nations, have not yet included green water resources.

It is argued in this study that, when analysing water involved in food production, it is necessary to consider not only the usual blue water resources but also green water resources. Only by including this fundamental source of agricultural water it is possible to determine the *actual* volumes of water available for food production. Chapagain and Hoekstra also put forward this approach (2004). Incorporating the concept of green water into water scarcity assessments has the potential to inform effective land use, water resources planning and management (Falkenmark and Rockström 2004; Aldaya *et al.* 2010a, 2010b).

The relationship between countries’ availability of green and blue water resources and the requirements for food production has been analysed by a few studies. In 1989, Falkenmark developed an index-based approach in order to understand the extent to which additional green water requirement could contribute to increase agricultural yields for food self-sufficiency in African countries. Rockström *et al.* (2007a) analysed the availability of green and blue water resources for food self-sufficiency in 92 developing economies, in relation to the attainment of the

Millennium Development Goal of hunger alleviation. Lundqvist *et al.* (2007) analysed the availability of green and blue water resources for meeting changing food preferences, mainly in relation to the increased consumption of animal products.

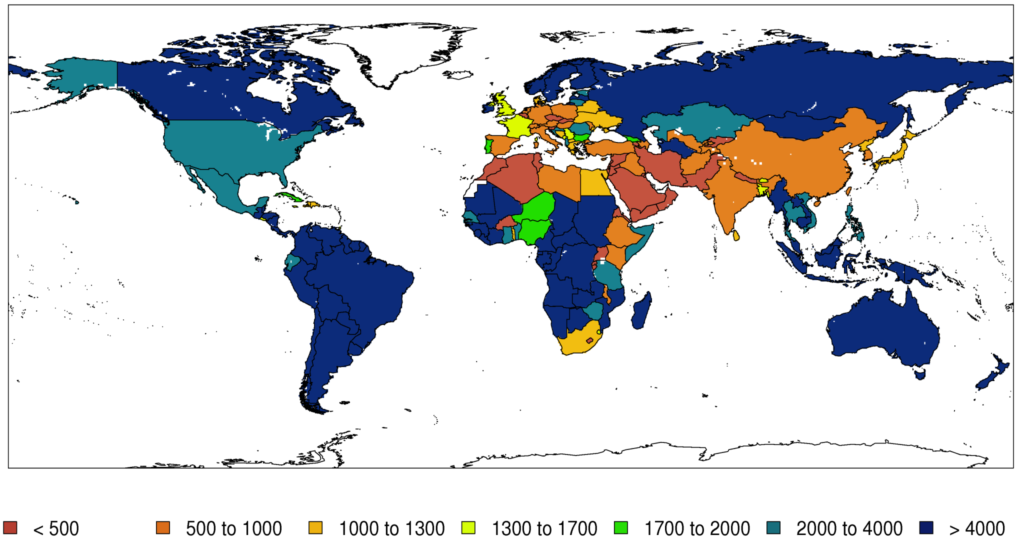
Water scarcity analyses have begun to integrate the green and blue water components only recently through the adoption of hydrological, ecological and crop models (Liu *et al.* 2007, 2009; Rost *et al.* 2008; Schoul *et al.* 2008; Siebert and Döll 2010). A very significant step towards water resource scarcity assessments has been achieved with the study developed by Rockström *et al.* (2009), which analysed global water availability for food production, by taking into account both green and blue water, both under present and future scenarios of population growth and climate change. A major finding of the study is that many of the world's economies that are generally considered as "severely water short" are instead able to meet the water requirements of their populations, if green water is "considered and (…) managed well" (*ibidem*: 1). The study predicted that, by 2050, 59% of the world population would be faced with blue water scarcity, and 36% by both green and blue water shortage. The study also emphasised that green (and land) water management is a good option to build resilience to future water conditions, without further expansion of croplands.

The study developed by Rockström *et al.* (2009) was built on the assumption that countries with less than 1,300 m^3 per capita per year of total blue and green water resources are *unable* to produce a target diet of 3,000 kcal per capita per day (with shares of 20% animal and 80% vegetal products), considered as a benchmark for hunger alleviation. The national calorie level of 3,000 kcal per person per day was chosen as a threshold for assessing water-for-food security for two main reasons. First, the number of undernourished people in a country tends to decrease towards zero when its population's average calorific daily intake reaches 3,000 kcal per capita (Rockström *et al.* 2005). Secondly, the world average food consumption will be approaching 3000 kcal per person per day in 2015, and will be just over 3,000 by 2030, and higher in 2050, mainly as a reflection of an increase in food consumption in developing countries (FAO 2003b, 2006).

As argued by Gerten *et al.* (2011), however, the threshold of 1,300 m^3 per capita per year may be valid only as a *global average* of water requirements, as countries' variations in crop water productivity are very significant. Crop water productivity is the ratio between crop yield and evapotranspiration during the growing period, and can be regarded as a parameter to assess the performances of both irrigated and rainfed agriculture. It varies significantly among regions due to differences in climate, soil humidity and water management conditions. As a consequence of differences in the specific conditions under which the crop is grown, significantly more or less than 1,300 m^3 per capita per year can be required to produce a diet of 3,000 kcal per person per day. Consequently, the adoption of a global average threshold underestimates water scarcity for regions where significantly more water is required to produce the standard diet (>1,300 m^3), and overrates water scarcity where less than 1,300 m^3 are needed.

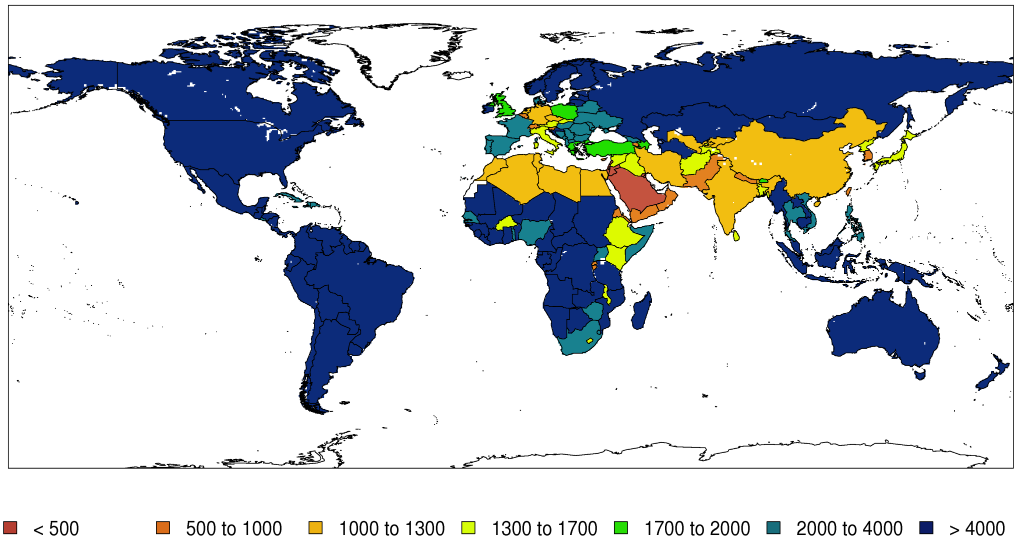
Drawing on these considerations, Gerten *et al.* (*ibidem*) developed a new water scarcity indicator that relates water requirements to produce a balanced diet of 3000 kcal per person per day, based on local crop water productivity, with the availability of green and blue water resources. The study demonstrated that, when only blue water is considered, water availability is less than 1,700 m^3 cap^{-1} $year^{-1}$ not only in world's water-deficit regions but also in densely populated countries (such as, India). Blue-water scarce countries include all the MENA economies. By contrast, in countries in the humid tropics, or where poor water endowments are combined with low population density (such as, Australia), blue water availability exceeds 4 000 m^3 cap^{-1} $year^{-1}$ (Figure 3.2). When also green water is considered, water availability becomes significantly higher, although some of the world's regions, such as the MENA, remain below 1 700 m^3 cap^{-1} $year^{-1}$ (Figure 3.3). The assessment carried out by Gerten *et al.* provides a key source of data deployed in the analytical Chapter 5 in order to assess food-water scarcity in the MENA countries.

Figure 3.2 Country-scale availability of blue food-water resources (m^3 cap^{-1} $year^{-1}$, 1971-2000)



Source: Gerten et al. (2011: 891)

Figure 3.3 Country-scale availability of total (green plus blue) food-water resources (m^3 cap^{-1} $year^{-1}$, 1971-2000)



Source: Gerten et al. (2011: 891)

3.3 Virtual Water: the overarching concept informing the study

Virtual water is the overarching concept informing the analysis. The following sections describe the concept of virtual water and its theoretical underpinnings. They also briefly review the literature that has originated since its inception, and illustrate its relevance for the study.

3.3.1 Virtual water: the *fil rouge* guiding the analysis of the MENA region's water question

The overall aim of the study is to draw attention and increase understanding of the political economy process beyond the traditional concerns of water sector professionals and scientists that have already, and will in the future, underpin the water and food security of the arid and semi-arid MENA countries. It is argued that economic forces and dynamics that lie *beyond* hydrology, water resources and the water sector that are the locus of water security in the region.

For these purposes, the present research will, first, provide a new assessment of food-water scarcity in the MENA economies by considering the availability of both blue (surface and groundwater resources) and green (soil) water resources to produce a targeted diet. Secondly, the study will situate the MENA region's water challenge in the broader context of international food trade, showing that economic systems have provided the region's economies with food-water security and have effectively alleviated the local water resource deficit. The study will argue that social 'adaptiveness' and economic diversification are the pre-requisites of food-water security in the region, and also the main factors that explain how available water resources are allocated and managed in the MENA political economies.

The concept of Virtual Water, identified by Allan in the early 1990s, is the *fil rouge* that runs through the whole research and informs the analysis developed in the following chapters. Virtual water is an "inherently economic concept" (Reimer 2012: 135), which highlights the water 'embedded' in food and non-food commodities, which ‘moves’ across boundaries as a result of international trade. The rationale of the concept is consistent with the principle of International Trade Theory as well as the Heckscher-Ohlin theorem, which predicts that international trade is largely driven by differences in countries’ resources (Krugman and Obstfield 2003).

The present study argues that unless the *whole* water resource available for food production is considered, any assessment of countries’ different endowments with regards to water resources will be flawed. This limitation affects a number of studies addressing the consistency of virtual water ‘trade’ and the Heckscher-Ohlin theorem (such as, Hakimian 2003 for the case of the MENA region). When assessing water resource availability it is in fact fundamental to include not only freshwater originating from surface and groundwater bodies employed in irrigated agricultural systems, but also soil water underpinning rainfed agriculture.

Food trade is the main vehicle of virtual water as food commodities are highly water-intensive. The production of a ton of wheat, for instance, requires on a global average about 1,000 cubic meters of water. Whereas, “a ton of wheat when imported by a water short political economy enables those managing scarce water in such economies to escape the economic and political stress of mobilising 1,000 tons (cubic meters) of water” (Allan 2003a: 9). This is the fundamental insight behind the conceptualisation of *virtual water ‘trade’.* As previously stated, the terms 'trade', 'flows', 'imports' and 'exports' when associated with virtual water will be used throughout with inverted commas, the reason being that, as pointed out by Merrett (2003a) it is in fact goods that are being traded, not water. Merrett’s critique of the terminology associated with virtual water ‘trade’ has been extensively countered by Reimer (2012) (more details will be provided in Section 3.3.3).

In recent years, the concept of virtual water has been the object of a flourishing literature (Bouwer 2000; Allan 2001; Earle 2001; Wichelns 2001; Allan 2002a, 2002c; Bouwer 2002; Yang and Zehnder 2002; Allan 2003a; Lant 2003; Merrett 2003a, 2003b; Wichelns 2004, 2005), and has steadily gained prominence at professional meetings and attention of policy-makers. It is a “genuinely transdisciplinary subject" (Hummel et al. 2006: 3), as it can be applied to both natural to social sciences, such as, geography, economics, political science, hydrology, and agronomy. Virtual water is also relevant for different actors, such as farmers, water managers and professionals, decision-makers and civil society. The concept has also attracted a number of critiques (among others, Merrett 1997, 2003a; Wichelns 2004; Ansik 2010). They are addressed in Section 3.3.3.

The concept of virtual water is deployed throughout the study for three main reasons. First, the concept enables us to appreciate the global dimension of water resource scarcity (Hoekstra 2011; Hoekstra and Mekonnen 2012), and to link consumers in water-deficit countries with producers and water resources in distant water-surplus economies. Vast amounts of water do exist in certain parts of the world and can be mobilised to secure the needs of water-deficit economies in the form of food imports. However, in water-surplus countries, water resources are consumed (and polluted) for producing export commodities, but neither the charges for water use nor the price of traded commodities reflect the economic and environmental cost of production. It is thus very unlikely that global production and trade patterns will be influenced by different water endowments and comparative advantage in water resources unless the value of water is recognised.

Secondly, the study uses the concept of virtual water to explain how the MENA economies have managed to cope with poor water endowments and have ameliorated local water deficits over past decades, and avoided conflicts over water (Allan 2002c; 2003a). Although international trade is not influenced by water scarcity, water scarcity *does* influence trade. Water-scarce countries are in fact forced to rely on the import of water-intensive commodities, such as foodstuffs, as the water available locally is not sufficient to meet local demands. This is the case for the MENA political economies that are all, net importers of agricultural products - grains in particular (Breisinger *et al.* 2010; Minot *et al.* 2010; Wright and Cafiero 2011). Grains are the main vehicles of virtual water 'imports' in the region, especially wheat as it has been shipped at half its cost of production for the past decades (Hakimian 2003). Arab countries are the largest net importers of cereals in the world (World Bank 2009a). Further liberalisation of global trade might double virtual water ‘flows’ between countries (Rogers 2003 in World Water Council 2004).

Thirdly, virtual water is very useful in drawing attention to the role that soil water also referred to as ‘green water’ invisibly plays in underpinning global water and food security. Falkenmark first identified green water in 1995, but its importance has been neglected in water resources assessments until very recently. It supports rainfed agricultural production as opposed to ‘blue water’, which is the water source for irrigated agriculture. Green water is highly correlated to a country’s precipitation pattern, soil profile and climatic conditions. According to Fader *et al.* (2011), green water accounts for the overwhelming majority of total water use in the agricultural sector (84%) as well as of the water ‘embedded’ in global exports of agricultural products (94%).

The present study draws on the concept of green water and it is argued that it must be included in any food-water scarcity assessment. It s inclusion also enables an assessment of the extent to which better green water management can contribute to the shift towards a more sustainable agricultural production in the region. It is also argued that, as green water productivity tends to be low on farms where the farmers operate in poverty and without the chance to respond to market demands, there is much scope for making better use of available green water resources in the MENA region, while relieving the pressure on blue water resources which have a much higher opportunity cost.

3.3.2 Defining virtual water: the water-food-trade nexus

Freshwater is an essential input in many production processes, particularly in the agricultural sector, which is the largest water user globally. On a global average, agriculture accounts for 70% of total freshwater withdrawals, and reaches up to 90% in a number of developing countries (WWAP 2012). Responsible water resource management in agriculture will thus be key to ensure future global water security.

Commodity exports/imports fundamentally act as channels to ‘transfer’ substantial amounts of water internationally in the form of an input ‘embedded’ in the exported/imported commodities via trade. This is the fundamental insight behind the concept of *virtual water*, which is at the heart of the global economic processes that ameliorate local water deficits in the MENA region and elsewhere. The concept had been previously called by Allan *embedded water*, but the term did not capture the attention of the water managing community and the general public until it was called ‘virtual water’ (Allan 2003a). Virtual water steps beyond the conventional understanding of ‘real’ water flows, to include an invisible political economy dimension that links global and national political economies (Warner and Zeitoun 2008). As stated by Allan (2003a), the World Bank started to use the term “water, food and trade nexus” in the mid 1990s, when the concept of virtual water was gaining currency.

Virtual water can be defined as the amount of water ‘embodied’ in products “not in real sense, but in a virtual sense” (Hoekstra 2003: 13) that are internationally traded between nations. If a country exports water-intensive products to another country, it also ‘exports’ the amount of water ‘embodied’ in those products, that is, virtual water. By virtue of these ‘flows’ of virtual water, water-abundant countries support water-poor countries so that they meet their water and food-related needs.

As suggested by Allan (2003a), the concept has both an *intensive* and an e*xtensive* component. The former describes the role of water in food production and the role of trade in providing food security; the latter instead, refers to the ‘invisible’ link that trade establishes between the source of water demand and the site of water consumption. Over the years, the concept has provided a useful analytical perspective for analysing how water-scarce nations achieve water security and has been variously applied as a ‘metaphor’ for describing the water ‘embedded’ in crops traded in the global market. It has played an important role in gaining the attention of public officials and in encouraging the consideration of scarcity values with regard to the inputs that produce goods and services when designing public policies (Wichelns 2005). The political dimension of the concept and the role it plays in solving geopolitical problems (Allan 1998a), and in mitigating conflicts over transboundary water (Zeitoun and Allan 2008), have been emphasised.

Two different approaches have been applied to provide a more precise quantitative definition of the term. In the first approach, the virtual water content of a commodity, good or service is defined as "the volume of water used to produce it, measured at the place where it was actually produced". In this case the adjective *virtual* "refers to the fact that most of the water used in the production is in the end not contained within the product" (Hoekstra 2008: 123). Accordingly, estimates of the virtual water content of a product must consider the place and period of production, the point of measurement, the production method and associated efficiency of water use, as they influence the amount of water used in the production chain (Hoekstra 2003). The second approach, defines virtual water as "the amount of water that *would have been* required to produce the product at the place where the product is needed" (Hoekstra 2003: 13 emphasis in the original). The former definition takes a producer perspective; whereas the latter emphasises the potential water savings brought about by virtual water 'trade' to the importing country.

In both the approaches, virtual water refers to the sum of the water that has been (or would have been) used to produce the commodity, good or service in the various steps of the production process, as opposed to the *real* water content of that product. The real water content of a product is generally far lower than the *virtual* water content, and so is the volume of water required by the transformation or processing of the product (Zimmer and Renault 2003). For instance, the virtual water content of a ton of wheat is, on global average, 1300 m^3; whereas the real water content is less than 1 m^3/ton (Chapagain and Hoekstra 2004).

The insight behind the concept could be usefully applied to any natural resource or other embedded input that moves across boundaries with the aim of measuring the external cost associated with the use of that natural resource. It has been applied, for instance, to capture the 'virtual' carbon content of imports and to investigate carbon emissions generated by foreign consumption, which are often referred to as ‘carbon leakage’ (Atkinson *et al*. 2010).

The concept of virtual water can be interpreted both as an analytical and descriptive concept, and as a political strategy. As an analytical concept, virtual water can be seen as a “medicine against undue ‘hydrocondia’”, i.e. the Malthusian argument that population growth will lead to water crisis (Warner in Hummel *et al.* 2006: 16). As a prescriptive concept, it has been highlighted that reliance on virtual water ‘trade’ to meet local water demands in water-short economies, can delay important allocative choices as well as political, economic, and ecological reforms (Allan 2001). Chapagain and Tickner (2012) have highlighted the role of the concept of virtual water as a tool for contextualising water resource policy options.

International political economy, however, makes virtual water as a policy prescription vulnerable to a variety shocks and pressures. The global food market is in not a level playing fields consisting of perfect competition, free trade and comparative advantage. The price of food in temperate zones does not reflect the cost of many inputs, such as labour, energy and water. Subsidies sustaining the agricultural sector, mainly in the EU and the US, do distort prices and have adverse impacts on agriculture in poor countries.

3.3.3 Economic theory and virtual water 'trade’

The aim of this section is to discuss water and its relationship with economic theory, and to review some of the critiques concerning the economic foundations of the concept.

Despite not originating within the economic literature, virtual water is an “inherently economic concept” (Reimer 2012: 135). The economic dimension of the concept has been stressed by Allan (1997b, 1998a, 2001, 2003b), who defined it as “something of a descendant of the concept of comparative advantage” (Allan 2003b: 8). According to the theory of comparative advantage (also referred to as

Ricardian model), a nation should export products in which it possesses a (relative) comparative advantage in production, while importing products in which it has a (relative) comparative disadvantage. In this context, it is important to distinguish between *absolute* advantage and *comparative* advantage. The former refers to a situation where a country or region can produce a good at lower absolute cost than its trading partner, while the latter refers to a situation where a country or region can produce the good at a less cost relative to other goods it produces when compared to its trading partners, regardless of absolute costs (Wichelns 2007). Comparative advantage considers internal cost ratios, whereas absolute advantage compares production costs across countries (Daly and Farley 2004).

The Heckscher-Ohlin model relates the comparative advantage of a country to the relative amount of primary resources endowments. It posits that an economy will be a net importer of the goods and services whose production is intensive in the factors that are relatively scarce within the country. Since primary factors include water resources, when the Heckscher-Ohlin model is applied to water it implies that a water-scarce economy will be an importer of water demanding goods. A number of studies have analysed the relationship between water endowments and agricultural trade flows (among others, Yang *et al.* 2003; De Fraiture *et al.* 2004; Yang and Zehnder 2008; Fracasso 2014; Debaere 2014) and water endowments and virtual water 'trade' flows (such as, Kumar and Singh 2005; Novo *et al.* 2009). These studies mainly aim to understand the extent to which water availability affects agricultural trade and virtual water international 'trade', often highlighting contradictory results with respect to the predictions of the Heckscher-Ohlin model. As usefully pointed out by Roson and Sartori (2010), however, trade patterns comply with the Heckscher-Ohlin model only in properly functioning and competitive markets, which is *not* the case for water resources. Water prices are in fact generally kept artificially low, possibly reversing the Heckscher-Ohlin theorem so that water-scarce countries turn out to be virtual water 'exporters' and, vice versa, water-rich countries are virtual water 'importers'.

Moreover, most of the existing Heckscher-Ohlin studies so far applied to the relationship between water endowments and virtual water 'trade' have not included the *green* water component, which plays a fundamental role in determining a country's comparative advantage in agricultural production. Given the importance of soil water in agricultural production at the global level, this limitation must have introduced misleading and inadequate results. In order to overcome this limitation, the study will assess food-water availability by considering the *whole* water resources available for food production in the MENA countries.

As Reimer put it, "we should not be surprised (...) if water is not a major determinant of trade patterns" (2012: 138) as water generally accounts for a share of production costs which is very small or often close to zero. Patterns of trade are driven largely by which country can be the low-cost producer to a given destination. For agricultural products, this is greatly affected by distance (freight costs) as well as tariff and non-tariff barriers to trade, which are also quite high in this sector (Man Li and Reimer 2010). Water resources in fact account for a tiny share of overall costs of production (Reimer 2012). Moreover, as pointed out by Tietenberg (2006), natural resource costs are not accounted for in the neoclassical production function, which considers only labour and capital inputs. For countries largely relying on rainfed agricultural production, water does not even enter into production costs (Ruhl *et al.* 2007). For this reason, relative water abundance in general is not a good predictor of international trade flows. A corollary of this statement is that the international trade system is not necessarily organized to achieve maximum water savings. Rather, they are driven by costs and consumer preferences (Reimer 2012).

The virtual water concept has attracted a number of critiques, especially from economists. One of the first economists to criticise virtual water was Merrett (1997, 2003a), who argued that there is not such thing as virtual water 'trade' as the amount of water contained in traded goods is always far lower than the totality of water that was used in their production. In his view, virtual water is thus only a 'metaphor' (1997) as it is *food* that is traded and not water. As pointed out by

Reimer, this statement, however, fundamentally overlooks the long and well-established tradition in international economics that view trade as "the international exchange of the *services of factors* embodied in goods" (2012: 135, emphasis in the original), which makes virtual water 'trade' the "import of the services of water" (2012: 135).

Reimer also showed that virtual water 'trade' is consistent with Vanek's (1968) extension of the Heckscher-Ohlin model, to multiple goods and factors. Vanek shows that interpreting trade in terms of "factor content exchanges", as opposed to trade in commodities themselves, allows one to obtain a number of interesting insights on what would be otherwise invisible phenomena. The term "factor content" of a product is defined by Reimer as "the total amount of a factor necessary to produce a good, which is likely to be more than the amount of a factor that a good contains when consumed in its final form" (2012: 137). Applied to water, the factor content indicates the amount of water used in the different phases of the production chain of a good, as opposed to the water that is actually contained in the product in its final form, which is generally very tiny if compared to the factor content. Drawing on this, the "factor content of a country's trade is calculated as the factor content of its consumption less the factor content of its production" (*ibidem*: 138). Consistent with the concept of factor content and with a long tradition of international economics, trade can thus be seen as an international exchange of the services of factors 'embedded' in traded commodities (Davis and Weinstein 2003), such as *water*.

Wichelns (2004) instead, criticised Allan (2003a) and Lant (2003) for drawing a close parallel between comparative advantage and the concept of virtual water. He claims that the concepts cannot be related in such way as virtual water addresses only water resource endowments, that is only *one* of the factors that should be considered when determining a country's comparative advantage, while ignoring the role of both opportunity costs and production technologies in influencing trade patterns. Reimer (2012) argues, on the contrary, that the virtual water concept is consistent with comparative advantage as a country's relative abundance (scarcity) of water endowments *does* represent a source of comparative advantage (disadvantage). However, this source of comparative advantage is often *latent* due to the very high costs and the policy-related trade barriers associated with agricultural trade, which fundamentally distort prices and obscure any potential comparative advantage (or disadvantage) arising from relative water endowments. As a result, the pattern of virtual water ‘trade’ deviates from the assumption of the Heckscher-Ohlin theorem and comparative advantage.

Another critique to the virtual water concept originated from Ansink (2010), who refutes the use of comparative advantages to evaluate the role of virtual ‘flows’ on global water savings. Ansink claims that trade can lead to water saving only if the country that has a comparative advantage in water also has an *absolute* advantage in the resource. In this context, if the exporting country has a relative advantage, while the importing country has an absolute one, then the latter will increase its already important water resources. This would explain why a number of water-rich countries, such as Norway or Switzerland, are net virtual water ‘importers’. These countries are in fact rich in the second factor of production, that is, capital, which gives them a comparative advantage in non-water intensive goods. Moreover, water resource endowments are often not associated with abundant arable land endowments. The positive correlation between a country's level of virtual water ‘exports’ and the amount of arable land per capita has also been emphasized by Kumar and Singh (2005).

Reimer (2012) confutes Ansink’s argument, demonstrating that an economic approach applied to virtual water ‘flows’ based on the theory of comparative advantages and the Heckscher-Ohlin model can be justified. He believes that the problem is that if the foreign country has more water in absolute terms but not in relative terms, then it must have more capital both in absolute and relative terms. The country thus benefits from more water but consumes relatively less water if compared to the rest of the world. Ansink also refutes the theory by assuming that a small country, specialized in water-abundant products, can always be a net importer of virtual water, if it imports enough capital-intensive goods. Reimer proves that the virtual water ‘exports’ intrinsic to the water intensive good will never be cancelled out by the water found in the capital-intensive goods.

According to Reimer, the existence of this limit is due to the consumers' budgetary constraints.

The virtual water concept has, therefore, a great deal of legitimacy when viewed from the perspective of standard international trade theory. As Reimer (2012) demonstrates any theoretical and empirical shortcoming associated with the concept of virtual water are due either to deviations from its theoretical assumptions, or arise because what happens in the real world deviates from the assumptions of economic theory. For this reason, a correct definition to avoid misconceptions, when referring to virtual water trade, is "trade in the services of water". "This type of phrase has indeed a long history of use by international trade economists, and recognizes that in trading goods across national borders, we are effectively trading the services of water that was used to produce the goods" (*ibidem*: 139).

3.3.4 Geopolitical considerations on virtual water 'trade'

Over time, a rich literature has addressed both the empirical and conceptual issues relating to virtual water 'trade'. A number of studies have suggested that the 'import' of virtual water can be regarded as an 'exogenous' source of water (Haddadin 2003) through which water-scarce countries can release the pressure on domestic water endowments and save water for 'higher' value uses such as for domestic purposes, industrial activities and environmental conservation (Lant 2003). Other studies have pointed instead, to the economic and political barriers that can have detrimental effects for poor economies in terms of 'dependency' and their food security, due to their vulnerability to the erratic fluctuation in world market prices (Biswas 1999; Wichelns 2001; Merrett 2003a, 2003b).

The transfer of *real* water over long distances is generally costly, whereas *virtual* water transfers in the form of commodity trade is economically feasible (Hoekstra 2003, 2008), especially in a world of low food prices, and can be mobilised very quickly (Allan 2003b). It is also economically *invisible* and politically *silent* (Allan 2001, 2003b). Using the 'import' of virtual water as a tool to secure food and water-related needs has thus become very attractive to a number of water-stressed countries (Zehnder *et al.* 2003). This is the case of many economies in the MENA region, where the volume of water available locally for food production has not been sufficient to meet increasing demands since the 1970s. Higher incomes combined with rapid population growth generated an increase in the demand for food, which could be satisfied only by increasing the levels of water-intensive food imports. The region has been importing nearly 40 million tonnes of cereals and flours yearly since the late 1980s (Allan 2001).

This virtual water 'trade' *solution*, however, has been scarcely acknowledged publicly. This has had three fundamental impacts. First, it has hidden the scope and the urgency of the water stress in the region. Secondly, it has enabled those responsible for making the impossibly challenging decisions associated with allocating water resources between sectors to avoid water-related political crises. Thirdly, it has hindered the process of change and implementation of reforms in the water sector. In other words, the procrastination of politically stressful reforms in the water sector has been enabled by virtual water 'trade', which provides politicians with a "dream solution" to water deficits, as it is "economically invisible and politically silent" (Allan 2002a).

As already pointed out in Section 3.3.3, it is not suggested that the idea of releasing domestic water is the main driver behind virtual water 'imports' (Hoekstra 2008), since international trade in agricultural commodities does depend on many more factors than relative water abundance or shortage. These factors are related to the availability of land, labour, knowledge and capital, as well as on a country's comparative advantage with respect to certain types of production, domestic subsidies and import taxes (Hoekstra 2007). Other factors are also the price for agricultural water and freight costs (Man Li and Reimer 2010; Reimer 2012). Global 'trade' in virtual water can thus only partly be explained on the basis of relative water abundance or shortage (De Fraiture *et al.* 2004).

3.3.5 Computation of virtual water 'flows' and the issue of virtual water savings

The basic approach for calculating virtual water 'trade was developed by Hoekstra and Hung (2002) when estimating the volume of crop-related virtual water 'flows' between nations over the period 1995-1999. Since then international virtual water 'flows' (generally measured in km^3 per year) have been calculated by multiplying commodity trade flows (tons/year) by their associated virtual water content (m^3/ton). The virtual water content of a product, in turn, can be defined as the volume of water required to produce the commodity in the exporting country (Hoekstra and Hung 2005). It is a function of crop water requirements, as estimated through the FAO Penman-Monteith equation, and yields. Virtual water 'trade' can thus be calculated as:

$$VWT\ [n_e, n_i, c, t] = CT\ [n_e, n_i, c, t] \times SWD\ [n_e, c]$$

In this equation, *VWT* is the virtual water 'trade' (m^3/year) from the exporting country n_e to the importing country n_i in year t as a result of trade in crop c. *CT* represents the crop trade (ton/year) from the exporting country n_e to the importing country n_i in year t for crop c. *SWD* represents the specific water demand (m^3/ton) of crop c in the exporting country.

It has been argued that virtual water 'trade' generates savings in virtual water 'importing' countries or regions (Chapagain *et al.* 2005a). These savings can be calculated as the volumes of commodities imported multiplied by the volumes of water that would be required to produce the goods locally. Virtual water 'trade' also entails *losses* for the exporting countries, as the water used to produce export goods will not be available locally for other purposes.

From a physical point of view, international trade can contribute to enhancing both local and global water use efficiency if water-intensive commodities are traded from areas of high water productivity, which results in products with low virtual water content, to areas characterised by lower productivity, thus resulting in global net water savings and global water use efficiency gains (Hoekstra and Hung 2002; Oki and Kanae 2004; De Fraiture *et al.* 2004; Aldaya *et al.* 2010a).

Chapagain (2008) argued that 352 Billion m^3 of water are saved annually as a result of international trade from water-productive sites to less productive sites, and also that a country's gain of a type of water does not necessarily result in the loss of the same kind of water. A recent study found that international agricultural trade saves blue water worth 2.4 billion US$ globally (Biewald *et al.* 2014). From an economic point of view, trade of products from water-efficient to water-inefficient countries can be beneficial depending on a number of factors, such as the source of the water being saved (green or blue water) as well as the differences in productivity with respect to other input factors, such as land and labour. The opportunity cost of the water being saved should also be more or equal to the price paid for it (Chapagain 2006).

In order to evaluate whether these savings are realistic or not, it is necessary to look at the national context of the virtual water 'importers', as national water savings have different implications for different countries. If a country saves water for products it could not produce itself, a reduction in import of these commodities may not create additional pressure on local water resources (this is the case of Germany's import of stimulant crops which could not be produced locally due to the lack of other production factors). On the contrary, in the case a reduction in imports would put additional pressure on local water resources, the implications from a national policy-making perspective are substantial (this is the case of Egypt's import of wheat, whose local production would also be completely blue-water sourced). For an importing economy is essential to see whether the marginal benefits and the impact on social wellbeing of importing water-intensive commodities, measured as economic games, are higher than the cost to import these commodities (*ibidem*).

Reimer (2012) argues that trade enables water-scarce countries to consume *more* water than is available locally, as it brings about an enhanced capacity for water-scarce country to "consume the services of *more* water". In order to be able import water-intensive commodities, a country will have to specialize on less water intensive products and sell them on the international market. This specialisation allows this country to consume more of the goods that use intensively the factor of production (in this case, *water*) of which they have relatively little. Virtual water 'importers' thus do not actually "save water" but, through trade, they are enabled to consume *more* water than is available locally. Consistently with this view, the present study argues that while there is *no* actual water saving in commodity trade, trade does enable very significant advances in food and water security to be achieved, as the capacity to engage in trade provides water-scarce countries, such as the MENA economies, with water and food security. Virtual water 'trade' is thus a securitising rather than a 'saving' process (Antonelli *et al.* 2012).

It has been argued that virtual water 'imports' in crop products have increased the overall 'water supply' and released blue water from irrigated agriculture to higher-value uses. As pointed out by Aldaya *et al.* (2010a), in the main exporting countries of wheat, corn and soya beans, agriculture is heavily dependent on green water resources, whereas most importers would have had to rely on their blue water resources in the absence of such imports. On the other hand, international trade of agricultural goods has exacerbated blue water scarcity in some virtual water 'exporting' economies, especially in Southern Europe, as the politically determined price for irrigation water does *not* reflect local water scarcity (Biewald *et al.* 2014).

Virtual water 'trade' has also increased overall water and water-dependent food security (Allan 2001; 2003b; 2003c; Aldaya *et al.* 2010a). The political concern generated by the public's perception on a nation's dependence on imports for securing its food and water-related requirements is an important argument behind the reluctance of public officials in the MENA region to acknowledge the role of virtual water 'imports'. The economies that are able to satisfy large proportions of their food needs may perceive a higher sense of security and stability than those that have to rely heavily on food imports. However, as Wichelns pointed out, "the cost of attaining that sense of enhanced national security may be quite high, as measured by the opportunity cost of scarce land, water and capital devoted to domestic food production" (2001: 134).

3.3.6 Global virtual water 'flows'

Over the past few years, six global studies have quantified the amount of virtual water 'flowing' across borders: Hoekstra and Hung (2002, 2005), Zimmer and Renault (2003), Oki and Kanae (2004), Chapagain and Hoekstra (2004); De Fraiture *et al.* (2004); and Hoekstra and Mekonnen (2012). The most recent estimates provided by Hoekstra and Mekonnen (2012) reveal that the global sum of international virtual water 'flow' related to trade in agricultural and industrial commodities in the period 1996-2005 accounted for 2,320 Gm^3/yr (km3/yr) on average, 68% of which originated from green (soil) water; 13% from blue (surface and ground-) water; and 19% from grey (polluted) water resources. The largest share is related to international trade in crops and derived crop commodities; whereas trade in animal and industrial products account for 12% each to global virtual water 'flows'. The volume of global virtual water 'flows' related to domestically produced products is 1,762 Gm^3/yr; whereas, the volume of total virtual water 'flows' related to the re-export of imported goods is 2,320 Gm^3/yr. Gross international virtual water 'flows' are illustrated in Table 3.1.

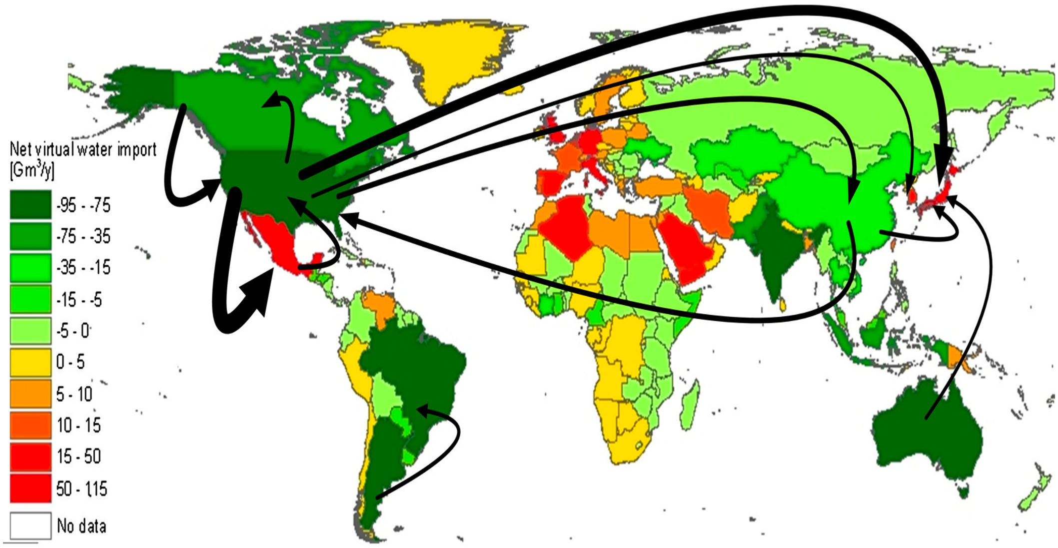
Table 3.1 Gross international virtual water 'flows' related to export and re-export of agricultural and industrial products (1996-2005)

	Agricultural products [Gm^3/yr]	**Industrial products** [Gm^3/yr]	**Total** [Gm^3/yr]
Export of domestically produced goods	1,597	165	1,762
Re-export of imported goods	441	117	558
Total	2,038	282	2,320

Source: Hoekstra and Mekonnen 2012

The major gross virtual water 'exporters' are the USA, China, India, Brazil, Argentina, Canada, Australia, Indonesia, France, and Germany. Together, these countries account for more than half of global virtual water 'exports'. Some of these economies (the United States, India, Australia and China) are, among others, the largest blue virtual water 'exporters', accounting for 49% of global blue virtual water 'exports' although they are all partially under water stress. The major gross virtual water 'importers' are instead the USA, Japan, Germany, China, Italy, Mexico, France, the United Kingdom, and The Netherlands. As illustrated in Figure 3.4, the biggest net 'exporters' of virtual water are the USA, Canada, Brazil, Argentina; India, Pakistan, Indonesia and Thailand; and Australia. The biggest net virtual water 'importers' are the MENA countries, Mexico, Europe, Japan and South Korea.

Figure 3.4 Virtual water 'balances' (1996-2005)



Source: Hoekstra and Mekonnen (2012: 3235)

To sum up, the concept of virtual water is deployed in this study as it provides a unique analytical perspective to analyse how water-deficit economies meet their water requirements for food and achieve water security. Global trade establishes an invisible link between the source of water demand and the site of water consumption. The capacity to engage in trade, however, is asymmetric and depends on socio-economic development. The extent to which water-stressed countries, such as the MENA political economies, will be able to diversify and strengthen their economies will determine their capacity to solve their water scarcity problem in the future.

3.4 Political economy, the 'sanctioned discourse' and the concept of 'procrastination'

Political Economy is a complementary framework informing the study. This approach is deployed throughout in order to draw attention on the economic processes that underpin food-water security in the MENA region, and to grasp the relationship between food-water security and socio-economic development. The relationship of the economy to the environment, including water, is as "the leaf to the tree" (Green 2003): that is, decisions concerning the environment and the effectiveness of their implementation determine whether environmental sustainability is achieved or neglected. Economics, that is, the application of choice, offers a useful means of understanding both the nature of the choices that are made and the potential for making better choices.

The origins of political economy can be found in the writings of scholars such as Hobbes, Smith, Ricardo, and Marx. In "The German Ideology" (1846), Marx and Engels defined the problematic dialectic between individuals, their productive activity in human society, and nature by asserting the importance of considering the productive activities of individuals as critical components of human-environmental interactions. This proposition draws attention on political economy, as it transforms and is transformed by individuals and nature.

Political Economy has been the object of a wide range of definitions through time. In the nineteenth century, John Stuart Mill defined it as "the science which traces the laws of such of the phenomena of society as arise from the combined operations of mankind for the production of wealth, in so far as those phenomena are not modified by the pursuit of any other object" (2009 [1848]: 129). Later definitions focus, instead, on the relationship between means and ends. Robbins defined economics as the discipline analysing "human behaviour as a relationship between ends and scarce means which have alternative uses" (2007 [1932]: 16). Similarly, Samuelson referred to it as "the study of how men and society end up *choosing*, with or without the use of money, to employ *scarce* productive resources which could have alternative uses, to produce various commodities and distribute them for consumption, now or in the future, among various people and groups in society" (1970: 4, emphasis in the original).

Posner defined it as "the science of human choice in a world in which resources are limited in relation to human wants, explores and tests the implications of assuming that man is a rational maximiser of his ends of life, his satisfactions what we call his 'self-interest'" (1977: 3); whereas in the late 1990s, Hausman defined economic phenomena as "the consequences of rational choices that are governed by some variant of consumerism and profit maximization. In other words, *economics studies the consequences of rational greed"* (1992: 95, emphasis in the original). The pithiest and probably most appropriate definition of economics to this study is that given by Green and Newsome (1992), who presented it as "the application of reason to choice".

Defining economics as the application of economic reason to choice shifts the burden to defining 'economic reason' and 'choice'. If economic reason is regarded as a logical framework of argument that determines what course of action should be adopted (Green 2003), then economics conceived as "the application of [economic] reason to choice" should lead to the choice of the best means of achieving some predetermined objectives. This argument is consistent with the neo-classical assumptions of individual rationality and utility. People seeking to maximise their individual utility have rational preferences among outcomes that can be identified and measured, that is, associated with a value. In other words, it is assumed that the objectives are given and that therefore choice does not involve a choice among different objectives.

However, the complexity of making choices in the real world lies precisely in that people have to choose between different and opposing objectives, especially in the case of scarce and competing resources. Echoing Kant (2009 [1785]), the challenge is therefore to apply reason to determining *what* our objectives should be, and then *make a choice* among those different options. Following this argument, once the logical argument leads to a conclusion that should be preferred to all others, the choice can be made. However, consideration of economic efficiency and rationality may not be the most important factors in orienting the allocation and management of scarce natural resources, including water. This holds particularly true in the MENA region, where the values of water resources are socially constructed and politically managed (Allan 2001).

Methods of weighing and appraising natural resource allocations cannot explain many of the present uses of resources. Echoing White, "one of the pervasive problems in resource management today is the widening gap between practice and knowledge" (1986 [1961]: 144). Although there are instruments for defining optimal combinations of complementary uses of water resources, the way water is allocated and managed is more driven by *politics* than by consideration of economic efficiency and sustainability. Water allocation, management and policy are subject to priorities shaped by expressions of *power*. Access to natural resources favours the most powerful actors, who are both wealthy and well connected politically (Forsyth 2003; Swyngedouw 2005).

Consistently with the three faces of power identified by Lukes[12] (2005 [1974]), power in its most explicit form can be defined as "the material capability of one party to gain the compliance of the other" (Zeitoun 2008, Zeitoun and Allan 2008: 7). Applied to transboundary water relations, for instance, a State's riparian position could be considered as an asset of 'hard' or 'structural' power. The second dimension of power refers instead, to control over the rules of the game, which not only determine the decisions that will be taken but also the non-decisions, that is the issues that are in fact excluded from the agenda. This dimension of power has been referred to as 'bargaining power'. (Zeitoun 2008) The third dimension of power refers specifically to the power that prevents people from having grievances by shaping their perceptions, cognitions and preferences in such a way that they accept their role in the existing (and politically-driven) order of things. This power thus, largely involves ideas, and is often referred as 'ideational power'.

[12] The relevance of Luke's three dimensions of power in hydropolitics and international transboundary water relations was first identified by Ana Cascao and then developed by the London Water Research Group (Zeitoun and Allan 2008).

It is argued that the faces of *power* cannot be ignored when dealing with water resources development, management and policy. Rather than flowing to the sea under gravity, water seems to flow uphill to *money* (Reisner 1986) and *power* (Allan 2001). As Zeitoun and Allan (2008: 6) put it, "those with power can mobilise resources to motivate engineers to move water from where Nature would deliver it to where privileged social groups choose to use it". Access to natural resources, water included, is determined by power and favours the most powerful. This proposition has historically underpinned the Hydraulic Mission, that is, a paradigm of water resource development characterised by large-scale mobilisation of water through engineering infrastructures, and centralised coordination and management. This paradigm is mainly driven by economic imperatives, such as the promotion of agricultural growth, increasing urbanisation and consumption (Allan 2003b).

In the MENA region, *politics* determine the terms of engagement over truth construction of and the level of social awareness of the water problem (Allan 2001). Politics determine *what* can be said about water, *who* can say it and *how* it may be interpreted by society, "thereby leading to the creation of a dominant belief system or paradigm" (Turton 2000b: 3). The notion of 'sanctioned discourse' refers to the prevailing or dominant ideas and narratives that are discursively and politically legitimised by certain actors, groups or states, and through which public attention is diverted and manipulated (Gramsci 1971; Hajer 1997; Allan 2001, 2003d). These actors, who are by definition the most powerful, deliberately emphasise or de-emphasise certain issues or perspectives on water resources according to vested political interests. Knowledge construction, that is the capacity to control and sanction the available data, information and knowledge, is a "variant of sanctioned discourse" (Zeitoun and Warner 2006: 448), as well as 'silentisation' (Greco 2005), a process through which particular information or events are underplayed or depoliticised.

Applied to water resources, the notion of the sanctioned discourse can be understood as the discourse that, if left unchallenged, will prevent remedies to water problems being addressed by appropriate strategies and sound reforms. A number of instances of sanctioned discourse in the MENA region have been identified by Allan (2001; 2002a; 2002b; 2002c; 2003a; 2003d). As he argues, public perceptions and public awareness of water issues in the region are *constructed* and subordinated to the imperatives of the prevailing sanctioned discourse of "non-awareness" (2003a: 5). The reason this constructed perspective has endured thus far lies in the operational effectiveness of the virtual water 'solution' which has, over the past decades, made invisible the region's water deficit and *silenced* the potential politics were the deficit to be evident. The impact of food imports, that is also an implicit 'import' of the water 'embedded' in the traded products, has been perverse in that the availability of virtual water in the global system has contributed to slowing down the pace of reforms and allowed the maintenance of the *status quo* in the MENA water sectors (Allan 2001).

A feature that appears to be common in the experiences of the water-deficit MENA economies, although to different extents, is a tendency to *procrastination* in decision-making with regard to water policy and the implementation of sound reforms. The concept of *procrastination* was introduced by George Akerlof, one of the central figures in Behavioural Economics and 2001 Nobel laureate in Economics. Drawing on cognitive psychology and economics, Akerlof (1991) theorised individuals' procrastinatory behaviour as the result of both reiterated errors of judgment of cost and benefits relative to others, and the influence that (socially constructed) cognitive structures have on action and decision-making.

Economic science, as defined above, assumes that individuals are always knowledgeable about their decisions and behaviours, which are assumed to be rational and utility-maximising. But, different, incoherent modes of individual and collective behaviour are, on the contrary, more than common in various contexts. The assumption underlying this argument is that individuals and groups possess cognitive structures, which are only dimly perceived by themselves but are nonetheless crucial in determining their behaviour as decision-makers.

"Procrastination occurs when present costs are unduly salient in comparison with future costs, leading individuals to postpone tasks until tomorrow without foreseeing that when tomorrow comes, the required action will be delayed yet again" (Akerlof 1991: 1). The term procrastination therefore refers to a situation in which "there are repeated errors of judgment due to unwarranted salience of some costs and benefits relative to others. In this case each error of judgment causes a small loss, but these errors cumulatively result in large losses over time" (*ibidem*: 3). These situations involving inconsistent choices and actions challenge the standard assumption of rational and utility-maximising behaviour of individuals and are "common causes of social and economic pathology" (*ibid.*). In each case, as Akerlof stated, "individuals choose a series of current actions without fully appreciating how those actions will affect future perception and behaviour" (*ibid.*). Present benefits and costs may be "unduly salient" vis-à-vis future costs and benefits. The procrastination can be costly: small salience costs can result in costly procrastination. The analysis of "behavioural pathology" is fundamental for the purpose of unravelling "how such pathology affects the performance of individuals and institutions in the economic and social domain" (*ibid.*). This procrastinatory behaviour is both an obstacle to the promotion of change and implementation of reforms in the water sector, and an intrinsic characteristic of the political economy in the MENA region. The reliance on virtual water 'trade' in the MENA enables policy-makers to procrastinate politically-challenging reforms in the water sector (Allan 2001).

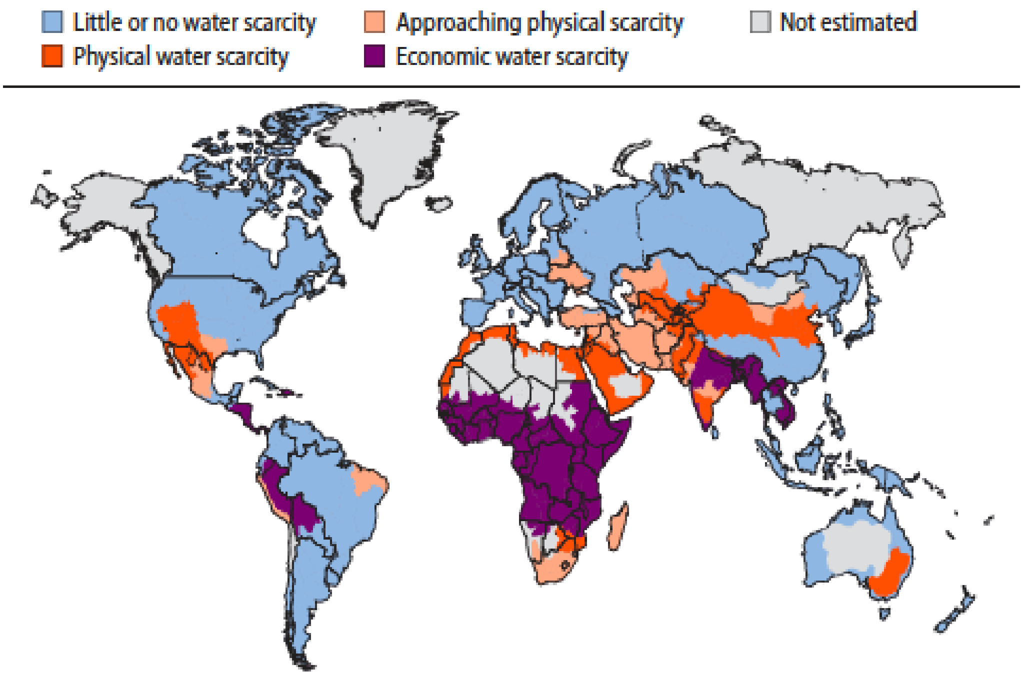
3.5 The theory of Social Adaptive Capacity

This section is concerned with the theory of Social Adaptive Capacity conceptualised by Ohlsson (1998; 1999). This theory will be deployed throughout to investigate the relationship between physical water scarcity, socio-economic development and water security. Consistently with the work of other scholars (Ohlsson 1999; Turton 1999; Ohlsson and Turton 1999; Turton 2000a, 2000b), particularly Allan (2001; 2006), the study argues that a country's capacity to meet its water needs is *not* determined by local water endowments but, rather, on the capacity to adapt to water scarcity. A major contribution of the present study is that this argument will be supported by considering water scarcity as the availability of total water resources that contribute to food production, that is green and blue water resources, thus overcoming the limitations of previous studies seeking to measure social adaptive capacity in relation to water resources considering blue water only (Earle 2001).

Water can be available in a "range of volumes from abundance to scarcity" (Turton 2000a: 7). Water can be scarce in usability, access or *entitlement* (Sen 1981). The United Nations (2007: 4) described water scarcity as "the point at which the aggregate impact of all users impinges upon the supply or quality of water under prevailing institutional arrangements to the extent that the demand by all sectors, including the environment, cannot be satisfied fully". This seemingly physical phenomenon is a by-product of the complex interaction between political, social, economic and environmental factors.

Water scarcity, defined in terms of "access to water" (Molden 2007: 10), can thus be either physical or economic (Figure 3.5). The former can be defined as the incapacity of water systems to meet all demands, including environmental flow requirements. Physical water scarcity can be found not only in the arid and semi-arid regions of the world, but also in areas where water is over-allocated (mainly in irrigated agriculture) and exploited far above sustainable levels. Physical water scarcity affects 1.2 billion people in the world and manifests itself as environmental degradation, declining groundwater levels, and inequality in water allocation. As illustrated by Figure 3.5, the MENA region is already facing or approaching physical water scarcity. Economic scarcity of water resources can be defined as the lack of investments or the lack in human, institutional, and financial capacity to meet water demands. It affects 1.6 billion people in the world and is mainly concentrated in Sub-Saharan Africa and South-East Asia.

Figure 3.5 Areas of physical and economic water resource scarcity



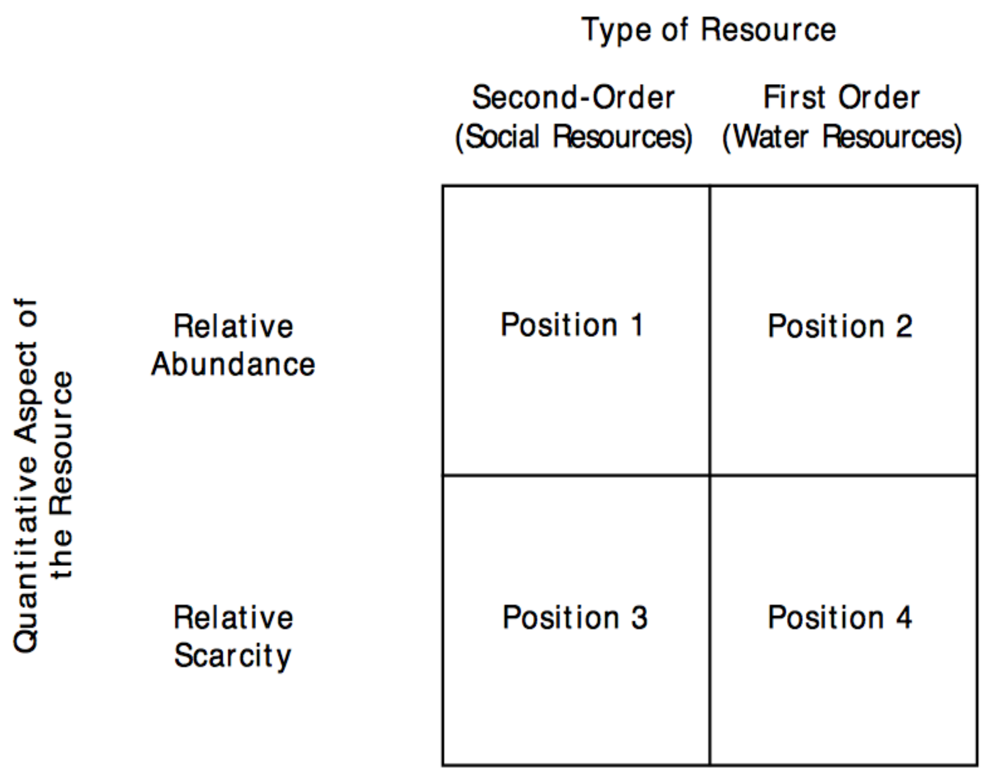
Source: Molden (2007: 11)

Secure and diversified political economies generally have options to cope with scarce water endowments, namely the 'import' of virtual water as well as the development of desalination facilities. These options or coping strategies are not available to poorly developed and poorly diversified regions of the world facing. In this sense, water poverty does not determine water insecurity; whereas poverty *does* determine water insecurity. As scarcity is often combined with problems related to socio-economic development and diversification, it is thus in the arid and semi-arid developing regions of the world that the problems arising from water deficits are most acute.

The experience of the MENA economies is very rich in demonstrating that water security is only *partially* determined by physical endowments. While self-sufficiency is totally related to endowments ('first order resources'), water security is very closely related to "the ability of a given social entity to adapt to changing levels of *water deficit* over time" (Turton 2000a: 7, emphasis in the original). First-order (or physical) resource scarcity can thus be solved by means of second-order (or social) resources. A social resource refers to the need to find appropriate tools and strategies to deal with the social consequences of first-order scarcities (Ohlsson 1999). Second-order resources determine the *social adaptive capacity* of a political economy (Turton and Ohlsson 1999) and are in fact "the defining ones when it comes to effectively managing *water deficit* in developing countries" (Turton 2000a: 7). Figure 3.6 illustrates the four levels of first and second-order resource scarcity identified by Turton and Warner (2001):

- Structurally-induced relative water scarcity (position 1);
- Structurally-induced relative water abundance (position 2);
- Water poverty with relative first-order resource availability (position 3);
- Water poverty with relative second-order resource availability (position 4).

Figure 3.6 First and second-order resource matrix



Source: Turton and Warner (2001: 54)

The distinction between first and second-order resources makes it clear that what shapes water security is not so much the availability of water itself but, rather, the capacity of a given society to adapt to both short and long-term changes in the availability of that resource. The oscillation between a first-order scarcity of water resources and a second order scarcity of the social resources required to cope with water deficits has been defined as the "turning of a screw" (Ohlsson and Turton 1999; Ohlsson and Lundqvist 2000).

Adaptiveness is, in turn, very much dependent on the internal discursive policy processes on how to allocate (blue) water resources within a political economy, as well as on the extent to which the ecological stewardship of the water environment is developed. Such allocative prioritisation is affected by the 'flows' of virtual water and by whether policy-makers are aware of them (Allan 2001). Economic and social adaptive capacity thus manifests itself as the capacity to mitigate water deficits by means of water policy reforms. Israel provides an example of a highly adaptive political economy in the MENA region (Allan 1996a; 1996c; 2001).

In summary the study deploys the theory of Social Adaptive Capacity to show that the MENA countries will be able to sustain the virtual water 'solutions' and achieve water security by means of second-order socio-economic resources. 'Adaptiveness' can in fact lead to *structurally-induced relative water abundance* (Turton and Ohlsson 1999), as in the case of Israel and Singapore. In these contexts, virtual water acts as a 'bridge' in achieving water security (Earle 2001).

3.6 Research questions and hypotheses

The theoretical frameworks and concepts identified above fundamentally guide the research questions of the present study. This section identifies the specific research questions that the study aims to answer and the related hypotheses that will be tested in the analytical Chapters 5-7.

3.6.1 Research questions

The overarching research question of this study is: **How have the MENA economies coped with water scarcity?** And more specifically: **How have these MENA economies achieved their water and food security?** This section presents the subsidiary questions of the study, the main hypotheses, and the sub-questions related to each subsidiary question.

Subsidiary question 1: *To what extent can local water resources meet the food-water requirements of the MENA political economies?*

Main hypothesis: The study hypotheses that the MENA countries face food-water scarcity, although to different extents, as the water available locally is less than the water requirements for securing the production of an adequate daily calorific intake per person of a balanced share of animal and vegetal products. This hypothesis is tested in Chapter 2 and 5.

Sub-questions related to subsidiary question 1:

1.1 To what extent is the MENA region facing a water challenge?

1.2 How is the MENA region endowed with food-water resources? To what extent can local water resources meet the region's requirements for food production?

Subsidiary question 2: *What has been the role of international trade in meeting the water requirements of the MENA economies?* And, more specifically: *To what extent have the MENA countries relied on virtual water 'trade' to secure their food-water needs?*

Main hypothesis: It is hypothesised that the MENA countries are largely dependent on virtual water 'imports'. Population growth and changes in dietary preferences have driven an increase in the agricultural water footprints and in virtual water 'imports'. There is a correlation between virtual water 'import' dependency, socio-economic diversification and adaptiveness, food security and mineral resource endowments. This hypothesis will be tested in the analytical Chapter 6.

Sub-questions related to subsidiary question 2:

2.1 To what extent is freshwater appropriation related to the consumption of agricultural goods in the MENA region? What is the contribution of water resources from outside the region to the region's water footprint?

2.2 How has virtual water 'trade' in agricultural commodities evolved over the past three decades, both globally and in the MENA region?

2.3 What has been the structure of virtual water 'trade' in the MENA over the past three decades? That is, to what extent do the MENA countries 'exchange' virtual water between themselves and with the rest of the world?

2.4 Which have been the main virtual water 'trade' partners of the MENA economies?

2.5 To what extent have the MENA countries been 'net importers' of virtual water? To what extent are they dependent on virtual water 'imports' to secure their food needs?

Subsidiary question 3: *To what extent have green and blue water resources underpinned the MENA virtual water 'trade?*

Main hypothesis: The study hypothesis that the largest share of the virtual water 'flowing' to the MENA political economies is 'embedded' in traded commodities is *green water*, as the region's trade partners mainly produce under rainfed conditions. The reliance on blue water resources for producing agricultural commodities for export is relatively higher in the MENA economies than in their virtual water 'trade' partners. This hypothesis will be tested in Chapter 7.

Sub-questions related to subsidiary question 3:

3.1 How has green and blue virtual water 'trade' in agricultural commodities evolved over the past three decades, both globally and in the MENA region?

3.2 What has been the structure of green and blue virtual water 'trade' in the MENA economies over the past three decades? That is, to what extent have the MENA countries 'exchanged' green and blue virtual water between themselves and with the rest of the world?

3.3 Which have been the main green and blue virtual water import 'trade' partners of the MENA economies?

3.4 To what extent has the MENA region 'exported' virtual water in the different types of agricultural commodities? Which have been the main "channels" of virtual water 'outflows' from the region's economies?

3.5 To what extent have the MENA countries been 'net importers' of green and blue virtual water?

The next section provides a detailed description of the hypotheses that this study seeks to test.

3.6.2 Hypotheses of the study

This section summarises the hypotheses related to the sub-questions described in the previous section.

SUBSIDIARY QUESTION 1:

To what extent can local water resources meet the food-water requirements of the MENA political economies?

Sub-question 1.1: To what extent is the MENA region facing a water challenge?

Hypothesis 1.1: Chapter 2 (Background) has identified the scope of the MENA region's water questions *vis-à-vis* the driving forces and asymmetries observed in its political economies and addressed this sub-question. The study hypothesised that the challenges the MENA is now facing are not only related to the region's poor water endowments, but also to the combination of a number of factors that are driving, and will in the future, increased pressure on water resources. It has been shown that these challenges are mainly population growth, urbanisation, changing lifestyles and dietary habits – with an increase in the consumption of water-intensive foodstuffs, economic growth and finally, the expected changes in precipitation, evapotranspiration and temperature due to climate change. All these factors will drive a major increase in water demands, and thus call for a rethinking of the region's water resource management and policy in a more sustainable way.

Sub-question 1.2: How is the MENA region endowed with food-water resources? To what extent can local water resources meet the region's requirements for food production?

Hypothesis 1.2: The study hypothesises that the bulk of the MENA countries are water scarce, as local water requirements for the production of a targeted balanced diet of 3,000 kcal/cap/day (80% vegetal and 20% animal-based) exceed local water availabilities. Water quality concerns are out of the scope of the present study. Chapter 6 will address this question and assess food-water scarcity in the MENA region by including both green and blue water resources. This hypothesis is tested in Chapter 5.

SUBSIDIARY QUESTION 2:

What is the role of trade in underpinning the food-water security of the MENA economies?

Sub-question 2.1: To what extent is freshwater appropriation related to the consumption of agricultural goods in the MENA region? What is the contribution of water resources from outside the region to the region's water footprint?

Hypothesis 2.1: The study hypothesises that the consumption of agricultural goods accounts for the largest share of the water appropriated by the MENA economies. It is also hypothesised that a substantial amount of this water originates *outside* the region and is thus accessed through the 'import' of internationally traded goods. This hypothesis is tested in Chapter 6.

Sub-question 2.2: How has virtual water 'trade' in agricultural commodities evolved over the past three decades, both globally and in the MENA region?

Hypothesis 2.2: The study hypothesises that virtual water 'trade' has increased considerably over the past 25 years, both at the global level and in the MENA, especially as a result of an increased liberalization of trade and a downward trend in the price of food commodities. The study also hypothesises that the increase in the consumption of water as 'embedded' in agricultural products, observed in the MENA region, has largely been met through virtual water 'imports'. This hypothesis is tested in Chapter 6.

Sub-question 2.3: What has been the structure of virtual water 'trade' in the MENA over the past three decades? That is, to what extent do the MENA countries 'exchange' virtual water between themselves and with the rest of the world?

Hypothesis 2.3: The study hypothesises that the volumes of 'exchanged' virtual water 'embedded' in intra-regional agricultural commodity trade (*between* the MENA economies) are far lower than the volumes 'embedded' in extra-regional virtual water 'trade' (with the rest of the world). This hypothesis is tested in Chapter 6.

Sub-question 2.4: Which have been the main virtual water 'trade' partners of the MENA economies?

Hypothesis 2.4: It is hypothesised that the 'import' of virtual water, over the past 25 years, has been mainly extra-regional; whereas the 'export' of virtual water has occurred, to a large extent, intra-regionally. This hypothesis is tested in Chapter 6.

Sub-question 2.5: To what extent have the MENA countries been 'net importers' of virtual water? To what extent are they dependent on virtual water 'imports' to secure their food needs?

Hypothesis 2.5: It is hypothesised that the MENA countries have been major 'net importers' of virtual water over the past few decades, as the volumes of water 'imported' from the global system via agricultural commodity trade are bigger than the volumes of 'exported' virtual water. This hypothesis is tested in Chapter 6.

SUBSIDIARY QUESTION 3:

To what extent have green and blue water resources underpinned the MENA virtual water 'trade'?

Sub-question 3.1: How has green and blue virtual water 'trade' in agricultural commodities evolved over the past three decades, both globally and in the MENA region?

Hypothesis 3.1: The study hypothesises that green water is the main source of virtual water 'embedded' in agricultural commodity trade, both at the global level and in the MENA. It also hypothesises that blue water accounts for a substantial proportion of the virtual water 'exported' by the MENA countries, as their reliance on this source of water is relatively higher than that of their virtual water 'import' trade partners. Chapter 7 will test this hypothesis.

Sub-question 3.2: What has been the structure of green and blue virtual water 'trade' in the MENA economies over the past three decades? That is, to what extent have the MENA countries 'exchanged' green and blue virtual water between themselves and with the rest of the world?

Hypothesis 3.2: It is hypothesised that green water water dominates both extra-regional and intra-regional 'trade' in virtual water. It also hypothesizes that the blue water component is relatively more important in virtual water 'exports' and intra-regional virtual water 'trade', compared with its role in 'imports'. This hypothesis is tested in Chapter 7.

Sub-question 3.3: Which have been the main green and blue virtual water import 'trade' partners of the MENA economies?

Hypothesis 3.3: It is hypothesised that the main virtual water 'import' trade partners of the MENA region engage in agricultural production under rainfed conditions and that, as a result, the virtual water 'export' from these countries is mainly associated with green water. It is also hypothesised that the blue virtual water 'imported' by the MENA economies originates, to a considerable extent, from *within* the region and often takes place (both intra-regionally and extra-regionally) in circumstances of local blue water scarcity. This hypothesis is tested in Chapter 7.

Sub-question 3.4: To what extent has the MENA 'exported' virtual water in the different types of agricultural commodities? Which have been the main "channels" of virtual water 'outflows' from the region's economies?

Hypothesis 3.4: It is hypothesised that food – and *crops* in particular – dominate both 'exports' associated with blue and green water from the MENA to the rest of the world. This hypothesis is tested in Chapter 7.

Sub-question 3.5: To what extent have the MENA countries been 'net importers' of green and blue virtual water?

Hypothesis 3.5: It is hypothesised that green water dominates the virtual water 'imports' at the country level. It is also hypothesised that the relative importance of blue water in virtual water 'exports' is more significant than in virtual water 'imports'. This hypothesis is tested in Chapter 7.

Table 3.2 summarises the overarching research question, subsidiary questions, and sub-questions of the study, as well as its main hypotheses.

Overarching Research Question: How have the MENA economies coped with water scarcity? How have these MENA economies achieved their water and food security?		
SUBSIDIARY QUESTIONS	**SUB-QUESTIONS**	**MAIN HYPOTHESES**
1. To what extent can local water resources meet the food-water requirements of the MENA political economies? **Where it is addressed:** Chapter 2 and 5	1.1 To what extent is the MENA region facing a water challenge? 1.2 How is the MENA region endowed with food-water resources? To what extent can local water resources meet the region's requirements for food production?	The MENA countries face food-water scarcity, although to different extents, as the water available locally is less than the water requirements for securing the production of an adequate daily calorific intake per person of a balanced share of animal and vegetal products.
2. What has been the role of international trade in meeting the water requirements of the MENA economies? To what extent have the MENA countries relied on virtual water 'trade' to secure their food-water needs? **Where it is addressed:** Chapter 6	2.1 To what extent is freshwater appropriation related to the consumption of agricultural goods in the MENA region? What is the contribution of water resources from outside the region to the region's water footprint? 2.2 How has virtual water 'trade' in agricultural commodities evolved over the past three decades, both globally and in the MENA region? 2.3 What has been the structure of virtual water 'trade' in the MENA over the past three decades? That is, to what extent do the MENA countries 'exchange' virtual water between themselves and with the rest of the world? 2.4 Which have been the main virtual water 'trade' partners of the MENA economies? 2.5 To what extent have the MENA countries been 'net importers' of virtual water? To what extent are they dependent on virtual water 'imports' to secure their food needs?	The MENA countries are largely dependent on virtual water 'imports'. Population growth and changes in dietary preferences have driven an increase in the agricultural water footprints and in virtual water 'imports'. There is a correlation between virtual water 'import' dependency, socio-economic diversification and adaptiveness, food security and mineral resource endowments.
3. To what extent have green and blue water resources underpinned the MENA virtual water 'trade'? **Where it is addressed:** Chapter 7	3.1 How has green and blue virtual water 'trade' in agricultural commodities evolved over the past three decades, both globally and in the MENA region? 3.2 What has been the structure of green and blue virtual water 'trade' in the MENA economies over the past three decades? That is, to what extent have the MENA countries 'exchanged' green and blue virtual water between themselves and with the rest of the world? 3.3 Which have been the main green and blue virtual water import 'trade' partners of the MENA economies? 3.4 To what extent has the MENA 'exported' virtual water in the different types of agricultural commodities? Which have been the main "channels" of virtual water 'outflows' from the region's economies? 3.5 To what extent have the MENA countries been 'net importers' of green and blue virtual water?	The largest share of the virtual water 'flowing' to the MENA political economies is 'embedded' in traded commodities is *green water*, as the region's trade partners mainly produce under rainfed conditions. The reliance on blue water resources for producing agricultural commodities for export is relatively higher in the MENA economies than in their virtual water 'trade' partners.

Table 3.2 Research questions, sub-questions and hypotheses of the study. *Source: Author*

3.7 Conclusions

This chapter has illustrated the main theories and concepts informing the present study. The concept deploys the concepts of food-water and non-food water in order to distinguish between the water used for food production and the water used by industry and households. The focus of the study is on the food-water, as it accounts for the largest share of water used by societies. This water can be either blue or green. One of the main contributions of the study is to shed light on the role played by green water resources in achieving a version of food security in the MENA countries.

The overarching concept informing the study is Virtual Water. Virtual water is the *fil rouge* guiding the study, as it effectively links water, food and trade. The whole analysis developed in the following chapters will be fundamentally informed by the virtual water concept. Political economy is a complementary framework that is used to draw attention on the invisible dynamics that lie outside the water sector but that do determine water outcomes. The study also deploys the theory of Social Adaptive Capacity in order to show that water outcomes are far more determined by economic capacity and social adaptiveness (second-order resources) than they are by water endowments (first-order resources). The following chapter presents the methodological approach of the study.

4. Methodological framework

4.1 Introduction

The aim of this chapter is to outline the methodology employed in the study in order to answer the research questions, subsidiary questions and sub-questions, identified in theoretical Chapter 3, and corroborate the related hypotheses. The chapter will also explain how the methods deployed have complemented one another throughout the different phases of the process of inquiry.

As anticipated in the Introduction (Chapter 1) and in the theoretical Chapter 3, the overarching aim of the study is to investigate the relationship between water and food security in the MENA region, answering the main research question of the study, i.e. ***How have the MENA economies coped with water scarcity?*** And more specifically: ***How have these MENA economies achieved their water and food security?*** This aim has been pursued not only by analysing the capacity of the MENA economies to meet their food needs; but also by investigating the extent to which the region's economies have relied on virtual water 'imports' to meet their food needs over the past two and a half decades. Three inter-related research questions were also identified, and are addressed in the three analytical chapters of the study (Chapter 5-7).

The main hypothesis of the study is that the MENA economies have relied to a large extent on international commodity trade, that is also an 'exchange' of water resources in virtual form, to secure the region's food needs, as the water available locally has not been sufficient to meet the water requirements for a balanced diet. The study aims not only to advance knowledge on the MENA water scarcity problems, but also to provide valuable insights for users and policy-makers. In order to achieve these aims, a *multi-method* approach, which combines both quantitative and qualitative elements, has been pursued and will be presented in this chapter.

The chapter is structured as follows: the second section describes the methodological approach and also highlights its relevance for the study. The third section is concerned with the methods and sources of data employed in order to answer the research questions. The fourth section addressed the ethics of the study. The concluding section draws some conclusions and also briefly reviews the structure of the study and the objectives of the chapters that follow.

4.2 Methodological approach

4.2.1 Preliminary considerations on methodology and methods

Methodology is a broad concept that "has deeper roots in the bedrock of specific views on the nature of 'reality' (namely, in ontology) and the grounds for knowledge (namely, in epistemology)" **(**Hoggart *et al.* 2002). The methodological approach of a study is the *strategy* deployed to answer research questions and test hypotheses, and also encompasses issues of methods, i.e. the specific *techniques* deployed for collecting and analysing data. The researcher can be seen as a "bricoleur", who creatively combine and integrates different theories, methodologies and perspectives (Denzin and Lincoln 2005). The *bricolage* is a critical research approach, whose origins can be traced back to the works of Levi's Strauss and that have then emerged in other strands of qualitative research (Rogers 2012).

Whatever method is employed, the use of that particular tool requires "a philosophical justification that guides interpretations of what knowledge is (ontology) and how it is derived (epistemology)" (Hoggart *et al.* 2002). It was shown in the theoretical Chapter 3, that Political Economy is the overarching framework informing the study. The value of this paradigm rests on both its generality and applicability to different fields of enquiry, as well as on its capability to provide a unifying and integrative framework that enables comparisons between major economic and socio-political constructs to be made. As the main theoretical framework guiding the research project, the political economy paradigm fundamentally influenced the choice of the methodology for developing the analysis and the methods deployed to collect and analyse key information and data. The choice of this paradigm has shaped the relationships between the three key elements of research – the research design (*theory*), the research strategy (*methodology*) and the research techniques (*methods*) – in the different phases of the process of enquiry. The next section presents the methodological approach of the study.

The methodological approach of the research can be defined as *mixed*, as both quantitative and qualitative methodology and methods have been deployed. The next sections will explain in detail the different techniques and data sources that have been employed and combined – complementing one another – in order to answer the research questions. The analyses presented in the analytical chapters have mainly been developed on the basis secondary-data collection. Data have been validated systematically through data triangulation throughout the whole research process. The specific sources of data deployed in the different chapters and data triangulation are discussed in Section 4.3.

4.2.2 Combining qualitative and quantitative analysis: a multi-method approach

This section presents the methodological approach and the methods employed in the study in order to answer the research questions and corroborate the related hypotheses (identified in Chapter 3).

The aim of the study is twofold. First, the study aims to provide a comprehensive analysis of the complex relationship between water and food security in the MENA region. Secondly, the study seeks to increase understanding on the role that international commodity trade has played, over the past 25 years in meeting the region's water requirements for food security. The study argues that the MENA economies achieve water and food security *outside* the water sector, as local water endowments do not meet the water requirements to achieve a zero net food imports. The analysis has examines the political economy processes that have underpinned water and food security in the MENA region, over the past two and a half decades, will be analysed.

The research mainly deploys a quantitative approach, although qualitative methods are also used. The combination of quantitative and qualitative analysis results in a *multi-method* or *mixed* approach, which result from the integration of a set of different research methods and aims to reach a "best of both worlds" (Bryman 1988). Mixed methods can be defined as "a design for collecting, analyzing, and mixing both quantitative and qualitative data in a study in order to understand a research problem" (Clark *et al.* 2008: 364). The combination of different approaches enables researchers to better understand the research problem being explored (Creswell 1994). As previously stated, the choice of the methodological approach has been largely determined by the research objectives of the study. This *mixed* approach has been pursued in order to analyse the multi-dimensional facets of the water challenge in the MENA in a comprehensive fashion. Triangulation, i.e. the combination of different methods in order to crosscheck data and increase robustness and validity of the analysis, has been essential for maximizing the understanding of the identified research questions and in underpinning the use of a *mixed* approach (Valentine 1997; Denzin and Lincoln 2005).

4.2.3 Quantitative approach

The aim of the present research is to provide a *comprehensive* analysis of the water-food nexus in the MENA by investigating how the region's economies achieve their water and food security. The approach employed in order to analyse the whole MENA region has been mainly *quantitative*. A quantitative research is "an inquiry into a social or human problem, based on testing a theory composed of variables, measured with numbers, and analyzed with statistical procedures, in order to determine whether the predictive generalizations of the theory hold true" (Creswell 1994: 2). Geography has included quantitative approaches since its institutionalisation as a scientific discipline in the nineteenth century (Barnes

2001), although its "quantitative revolution" is usually identifies as a phenomenon to the 1950s and 1960s (Marshall 2006). In applying quantitative methods, this research recognises that knowledge is situated and that, as such, the approach to research should be *reflexive* (Rose 1997 in *ibidem*).

The *quantitative* mode of enquiry employs numerical indicators and statistical analysis in order to ascertain the scope and the evolution of a particular phenomenon. As put it by Flick (2002), quantitative analysis can be useful in operationalising theoretical relationships and measuring phenomena. This research has deployed a quantitative approach in order to some of the research questions. For example, to what extent have the MENA countries been 'net importers' of virtual water? To what extent are they dependent on virtual water 'imports' to secure their food needs? Quantitative research emphasises "the measurement and analysis of causal relationships between *variables*, rather than *process*" (Lincoln and Denzin 2005: 8, emphasis added). In order to overcome this limitation, the study has also made use of qualitative methods, as explained in the following section. The strengths of the quantitative approach are mainly controlled enquiry, replicability of analyses, and the ability to produce causality statements (Hughes 2006). However, they fail to capture the nature of phenomena in their specific contexts (Burns 2000).

Despite the inherent uncertainties and limitations of quantitative analysis, the use of this approach has proved to be essential in achieving the main research objectives of the study, in analysing how the MENA economies have achieved water and food security over the past few decades (*overarching research question of the study*). The use of this approach has enabled the researcher identify the water and food-related problem in the region in specific and definable terms; and also to shed light on the role that water resources from *outside* the region have played in underpinning the region's food requirements by giving an indication of the water 'exchanged' at the international level as 'embedded' in the traded commodities. The use of this methodological approach has thus enabled the researcher to answer the research questions of the study and corroborate the related hypotheses.

The quantitative mode of enquiry has been used in all the analytical chapters of the study, in order to advance knowledge on the scope of the water supply deficit in the MENA countries; and also the reliance on virtual water ‘trade’ to secure the food requirements of the region’s populations. The quantitative data collection has covered three main aspects: water security and food security, agricultural trade, and socio-economic development in the MENA countries. The quantitative analysis carried out in this study is not only *correlational*, as it attempts to determine the relationship between two or more identified quantifiable variables; but also *cause comparative*, as it seeks to establish cause-effect relationships (Gay 1996). The specific sources of data deployed in the three analytical chapter of the study are described in Section 4.3.

4.2.4 Qualitative approach

The study has also deployed a *qualitative* type of investigation in order to better understand the context of interest, although the analysis developed is mainly quantitative. Qualitative research is an “empirical research where the data are not in the form of numbers” (Punch 1998: 4). The qualitative research approach “cannot be reduced to particular techniques nor to set stages, but rather that a dynamic process is involved which links together problems, theories and methods” (Bryman 2002: 2). It is primarily concerned with seeking to accurately describe, decode, contextualise and interpret the meanings of particular phenomena occurring in selected socio-political settings (Fryer 1991).

The use of qualitative methods has been particularly important in that it has enabled context-sensitive information to emerge. The emergence of this kind of information is important, especially as water in the MENA region is socially defined and its management is highly politicised (Allan 2001). The main method of qualitative data collection has been mainly documentary analysis. Qualitative data were also derived from participation in a number of conferences and meetings during the period of the study – 2009 to 2014.

The following section presents the methods deployed in the study and also relates them to identified research questions.

4.2.5 The research process: seven stages

The process of research has involved *seven* interrelated stages, which have involved both inductive and deductive reasoning. The *six* research stages are: 1) the formulation of the research questions; 2) the development of the analytical framework; 3) development of the methodological framework, consistently with the theoretical framework; 4) data collection; 5) data analysis and finally; 6) hypotheses testing and research questions answering; 7) thesis writing and dissemination.

The research process is “not a clear cut sequence of procedures following a neat pattern, but a messy interaction between the conceptual and empirical world, deduction and induction occurring at the same time” (Bechhofer 1974: 73 in Hoggart *et al.* 2002). Deduction can be defined as the “derivation of expectations and hypotheses from theories”; whereas induction is the “development of generalisation from specific observations” (Babbie 2007: 66). Both deductive and inductive reasoning has been deployed in an integrated fashion throughout the whole research process. The exposure to information, ideas and theories has in fact been functional in producing progressively new ideas and concepts to be deployed in the study, and has often raised the need to refine the analytical framework of the study against the data being analysed as well as to adjust the research questions. The seven research stages are described below.

Stage 1. Formulation of research questions: In this stage, the research questions and sub-questions were developed, informed by an extensive literature review conducted over the first months of my PhD and prior to commencing data collection. This phase was mainly deductive in nature. Hypotheses were also formulated in this phase.

The decision to focus on water resources in the MENA region was influenced, on the one hand, by some research experience on the political economy of water resources, which I gained prior commencing my research at King's College London and, more specifically, when writing my MSc theses at La Sapienza, University of Rome, and at the School of Oriental and African Studies (SOAS), University of London. On the other hand, the choice of the geographical scope of the study was influenced by my personal interest in the region.

During this stage, I conducted an extensive literature review on the topic, revising academic journals, reports and other sources of secondary data. My initial research questions and hypotheses were revisited a number of times not only over the first months of my PhD, but also after my upgrade meeting. The upgrade was the first important evaluation event of my work as a PhD candidate. This preliminary phase also immensely benefitted from the presentation of my first-year research outcomes to the department of Geography at King's College London.

Stage 2. Development of the analytical framework: The development of the analytical framework of the study has been possible after having set the main research question of the study and having conducted a preliminary analysis of the research context. Framing a strong analytical framework has been fundamental in that it has enabled me to overcome limitations of previous analysis of the MENA water security challenges. This phase was mainly deductive in nature, as facts were derived from theory (*top-down approach*).

Stage 3. Development of the methodological framework: Stage 1 and 2 informed this stage of the research. The methodological framework was in fact identified through the thorough definition of concrete and achievable research objectives, not only on the basis of previous studies on the topic of interest, but also through the identification of the available sources of data.

A pragmatic approach to research was employed for threes main reasons. First, the nature of the research questions as well as the testing of the hypotheses demanded quantitative approaches of investigation. Secondly, quantitative methods allowed relationships between variables to be understood. In particular, the study is concerned with the relationship between socio-economic and water-related variables in the MENA countries. The methods deployed in the study are statistical analysis, document analysis, and participant observation. The analysis is based on secondary data sources. More details will be provided in Section 4.2.4.

Both stage 2 and 3 of the research benefitted from an extensive participation, either as a presenter or observer in a number of conferences, meetings and seminars, which are listed in Table 4.1. Participation in these contexts prompted the development and enhancement of the analytical framework of the study and also provided the author with the opportunity to receive feedback on the research being developed. Participation in these events has also provided occasions to broaden significantly the network of the researcher. Finally, the involvement as a Research Fellow in the context of the EU project WASSERMed (Water Availability and Security in Southern EuRope and the Mediterranean), from April 2011 to February 2013, provided the author with the opportunity to focus on water policy and management in three MENA countries (namely, Egypt, Tunisia and Jordan) as projects' case studies; and also to build professional relationships which have proved to be essential for data collection (namely, with the Potsdam Institute on Climate Impact Research). More details on this aspect will be provided in Section 4.3.

Table 4.1. Main meetings and seminars attended

Date	Meeting type	Purpose of participation
05/2010	Seminar on "Environment Politics and Development" organised by the Department of Geography, King's College London, University of London.	Oral presentation
05/2010	5th International Hydro-Hegemony Workshop, organised by King's College London & University of East Anglia, held in London	Interactive participation

06/2010	Awakening Africa's Sleeping Giant workshop, School of Oriental and African Studies (SOAS), University of London, held in London	Interactive participation
09/2010	International Conference "World Water Week", organised by the Stockholm International Water Institute, held in Stockholm	Interactive participation
02/2011	International General Assembly of the EU-FP7 CLIWASEC research cluster, including the projects WASSERMed, CLICO and CLIMB, held in Cagliari, Italy.	Oral presentation
04/2011	International Conference of the project EU-FP7 WASSERMed project, held in Amman	Interactive participation
02/2012	International General Assembly of the EU-FP7 CLIWASEC research cluster, including the projects WASSERMed, CLICO and CLIMB, held in Munich, Germany	Interactive participation
08/2012	International Conference "World Water Week", organised by the Stockholm International Water Institute, held in Stockholm	Interactive participation
11/2012	6th EGU Leonardo Conference "Hydrology and Society", organized by Politecnico di Torino, held in Turin	Poster presentation
11/2012	Seminar on "Virtual Water and Water Footprint", organized by "Ingegneria senza frontiere", University of Florence, held in Florence	Oral presentation
11/2012	International Conference on "Food Security in Dry Lands", held in Doha, Qatar	Conference paper; Interactive participation
03/2013	Workshop "Water security in the Mediterranean region", Bocconi University, University of Milan, held in Milan	Oral presentation (and co-organiser)
04/2013	International Conference of the Association of the American Geographers, held in Los Angeles	Oral presentation
07/2013	Conference "L'industria agroalimentare incontra l'impronta idrica" organized by the Associazione Italiana Marketing (AISM) and Consorzio Ricerca Venezie, held in Venice	Oral presentation
09/2013	International Conference "World Water Week", organised by the Stockholm International Water Institute, held in Stockholm	Poster presentation
09/2013	One-week training for representatives of the Ministry of Agriculture and/or Water in the MENA countries, in the context of the "Regional initiative on Water Scarcity in the Near East" organized by FAO, held in Rome	Interactive participation (as a research assistant)
11/2013	International Conference "Water and the Green Economy", organised by the University of East Anglia and the ICID UK (International Commission on Irrigation and Drainage), held in London	Oral presentation
11/2013	Seminar "WAKHAN THANKA", Politecnico di Milano,	Oral presentation

	University of Milan, held in Milan	

Source: Author

Stage 4 and 5. Data collection and analysis: In this phase, data were collected and also in part analysed whole collection was occurring. This preliminary analysis of data was beneficial in that it enabled me to rectify and also devise new questions ad themes as the research developed. Data collection involved secondary data collection (mainly databases), grey literature and document analysis (these methods are described in more detail in the next section). The majority of data collection took place between January 2012 and June 2013.

The following phase (stage 5) consisted of systematic data analysis and review of the hypotheses. This phase was mainly inductive (*bottom up approach*). Triangulation enabled me to check my research outcomes through "convergence, corroboration and correspondence of results from different methods" (Darlington and Scott 2002: 121) and also to get a full picture of the phenomenon under investigation.

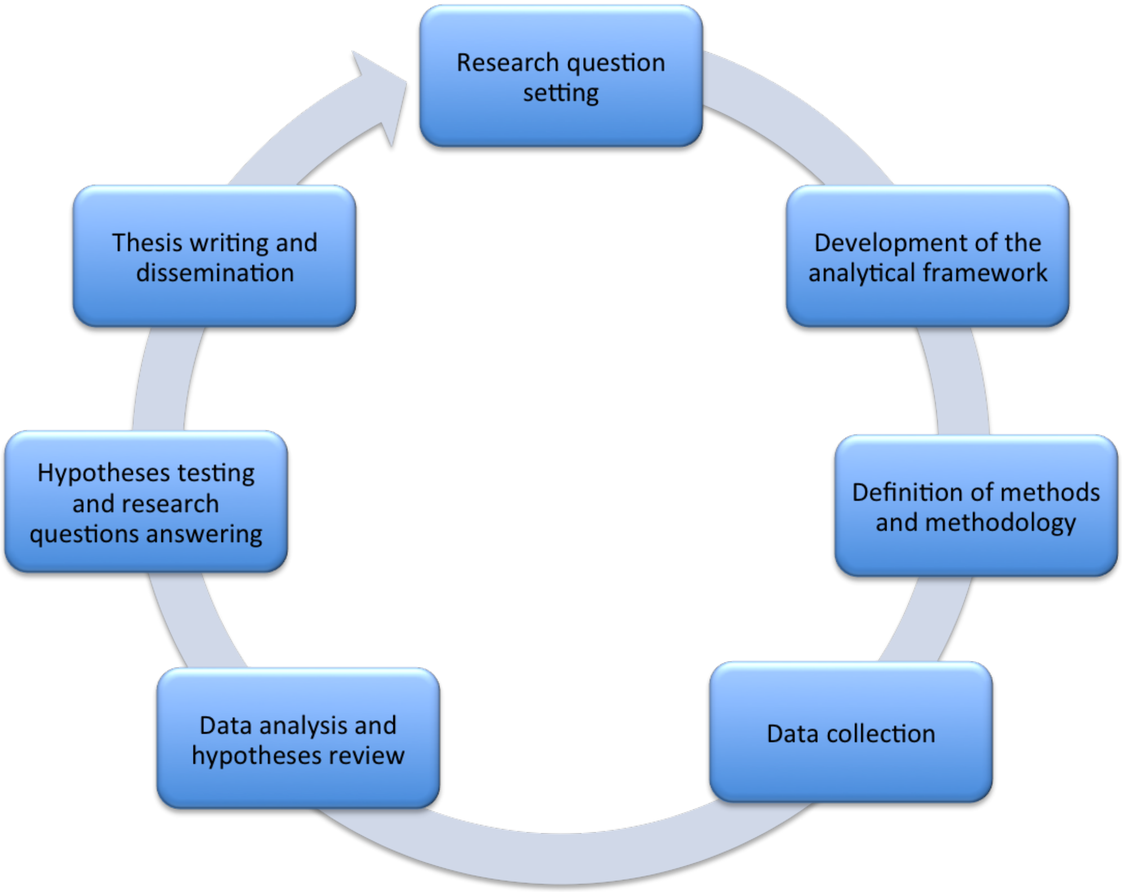
Presentations in international conferences and seminars (listed in Table 4.1), provided opportunities to test the data collected, as well as to receive feedback on my research approach and hypotheses. Finally, throughout the study, I have had important opportunities to test my research findings. I have been able to test part of my research findings while publishing a paper in the peer-reviewed journal *Water Resources Management* in 2012, and also co-editing a handbook on virtual water and water footprints (in Italian), in 2013. The publication of the edited book resulted in interviews with some major Italian newspapers and magazines, as well as in radio and video interviews. During the period of research, the author also published an article on the journal *L'Europe en formation* (2013) and also contributed a chapter to the edited volume *Handbook of Land and Water Grabs in Africa. Foreign direct investment and food and water security* (2013), and another on a *UN-Water report* on water security in the green economy (2012). Finally, the author has acted as a leading author of the first WWF-Italy report on *the Water Footprint of Italy*, released on the occasion of the 2014 World Water Day (22^{nd} March).

Stage 6. Hypotheses testing and research questions answering: This phase included the final analysis of the collected data, as well as the integration of data analysis and the theoretical framework of the study. The research questions of the study were answered during this phase, and the related hypotheses tested.

Stage 7. Thesis writing and dissemination: In this concluding phase, the PhD thesis was written and also dissemination activities were carried out. These activities included the submission of two articles. One of these articles will be published on a Springer edited volume on the issue of governance of environmental change and human security and is currently under revision. The other article will be presented in the international conference *"The Water-Food-Energy-Climate Nexus in Global Drylands",* organized by King's College London, the OCP Policy Centre, the Barcelona Centre for International Affairs and Texas A&M University that will be held in Rabat (Morocco) in June 2014, and will be published on a special issue of the *International Journal of Water Resources Development*, subject to a refereeing process.

The different stages of the research process are summarised in Figure 4.1. The next section will present the main data collection methods employed in the study.

Figure 4.1 The six stages of the research process



Source: Author

4.3 Methods

This section introduces the methods deployed in the study. Two important considerations have underpinned the choice of this set of tools: the research objective and the feasibility of the project. The term *method* refers to the specific techniques deployed for data collection. Method encompasses, according to Punch (1998), three phases: research design, data collection and data analysis. The choice of the methods is shaped by the way data are interpreted, i.e. by the methodological and theoretical framework informing the study (Hughes 2006). The present research is based on secondary data. The analysis of secondary data can be defined as "the further analysis of an existing dataset with the aim of addressing a research question distinct from that for which the dataset was originally collected and generating novel interpretations and conclusions" (Hewson 2006: 274). Secondary data require the development of a rigorous analysis as much as primary data (Menter *et al.* 2011). The following sub-sections describe the quantitative and qualitative secondary data deployed in this study.

4.3.1 Quantitative secondary data sources

This section presents the different quantitative secondary data sources employed in the study. Part of these data were accessed from databases available online. These data included, for instance FAO statistics on trade (FAOSTAT) and water resources (AQUASTAT), as well as data on water footprints from the Water Footprint Network. The most substantial part of secondary data sources of the study was collected by the researcher through the establishment of professional relationships with research centres and academic institutions in Europe. These institutions are, namely, the Potsdam Institute for Climate Impact Research (PIK) and the Polytechnic University of Turin. Data collection mainly took place between January 2012 and June 2013, and involved visits to Potsdam (Germany) and Turin (Italy). Data were provided mainly in the form of raw data. The author has benefitted from the interaction with the scientists from these institutions in the form of feedback and also professional cooperation, as the research developed. These aspects are summarised in Table 4.2.

Table 4.2 Research institutions, data collected and cooperation outputs

Research Institution	Main dataset collected	Cooperation output
Polytechnic University of Turin	Virtual water 'trade'; virtual water 'embedded' in production and consumption of agricultural products, both at the global scale and in the MENA.	Chapter submitted to edited book (currently under revision); Presentation in the international conference *"The Water-Food-Energy-Climate Nexus in Global Drylands"* (Rabat, 12-13 June 2014); Co-chaired the session "Water and food security: integrating perspectives from geophysics and social sciences" at the 2014 EGU (European Geoscience Union) General Assembly held in Vienna (1st May 2014).
Potsdam Institute for	Water availability and	Co-chaired the session "Water and food security: integrating perspectives from

Climate Impact Research	requirements for food production, both at the global scale and in the MENA.	geophysics and social sciences" at the 2014 EGU (European Geoscience Union) General Assembly held in Vienna (1st May 2014).

Source: Author

Table 4.3 provides a summary of the main quantitative secondary data sources deployed in the study. Each data source is related to the variables analysed, as well as to the research questions and chapters of the study. The original aspects of the analyses pursued in the study are also highlighted. The next sub-sections present the sources of data deployed for the main variables analysed in the analytical chapters of the study.

Variable analysed	Definition	Measurement	Data sources	Original aspects of the thesis	Chapter
Food-water scarcity	A country's capacity to produce adequate food with local water resources.	Capacity to produce a targeted diet with available water requirements, both in surface and groundwater and soil water resources, based on local water productivities.	Gerten *et al.* 2011	Assessment of **green and blue water availability** for food production by country in the MENA region. Promotion of a widened approach to water resources. Stress on the need to go *beyond* water supply management of blue water resources and to unlock the potential of green water resources.	Chapter 5 (Subsidiary question 1)
Water footprint of nations	Total amount of freshwater that is used to produce the goods and services consumed by the inhabitants of a nation.	Sum of water use inside a given country and water use outside the country.	Mekonnen and Hoekstra 2011a	Assessment **of water footprints of consumption** of the whole MENA region. Identification of the role that *agriculture* plays in the water consumption of the MENA economies.	Chapter 5 (Subsidiary question 1)
Virtual water 'trade'	'Exchange' in water in virtual form implicit in commodity trade.	Commodity trade flows converted in virtual water equivalents based on country-specific crop water requirements.	Carr *et al.* 2013; Tamea *et al.* 2013	Assessment of virtual water 'trade' in *all* the MENA countries (1986-2010). Virtual water 'trade' **partner** identification and analysis by **type of traded agricultural commodity.** Identification of **net 'imports'** by country.	Chapter 6, 7 (Subsidiary question 2 and 3)
Food-water dependency	Dependence on *external* water resources to secure a country's water needs.	Ratio between virtual water 'imports' minus 're-exports' over total water footprint of consumption of a given country.	Carr *et al.* 2013; Tamea *et al.* 2013	Understanding of the extent to which the MENA countries are **dependent** on water resources from *outside* the region.	Chapter 6 (Subsidiary question 2)
Green and blue virtual water 'trade'	Virtual water 'imports' in soil water and groundwater and surface water.	Green and blue water virtual water 'flows' are differentiated on the basis of the footprint estimates provided by Mekonnen and Hoekstra (2011a).	Carr *et al.* 2013; Tamea *et al.* 2013	Assessment of green and blue virtual water 'trade' in the MENA in its **temporal dynamics** (1986-2010). Virtual water 'trade' **partner** identification and analysis by **type of traded agricultural commodity.** Identification of **'imports' and 'exports'** of green and blue virtual water by country.	Chapter 7 (Subsidiary question 3)
Socio-economic 'adaptiveness'	The socio-economic-institutional capacity to adapt to water scarcity.	Human Development Index	UNDP 2013; Turton 1999	Analysis of the relationship between societal development, water scarcity, food trade and water resource security. Broader understanding of the role that "second-order" (socio-economic institutional) resources play in shaping "first-order" (water) resource security.	All analytical chapters (all subsidiary questions)

Table 4.3 Overview of quantitative secondary data sources and their relevance for the study. *Source: Author*

4.3.1.1 Food-water scarcity assessment

The study by Gerten *et al.* (2011) is the main source of data deployed for assessing food-water scarcity in the MENA region, which is the specific focus of the first analytical Chapter 5. Gerten *et al* (2011) developed a new water scarcity indicator that related water scarcity to a country's capacity to produce a balanced diet of 3,000 kcal (assumed to consist of 80% vegetal and 20% animal-based products) per person per day, based on local crop water productivity, with the availability of green and blue water resources.

Data were provided to the author by the Potsdam Institute for Climate Impact Research (PIK). Data collection and analysis took place in the first six months of the year 2012. The volumes of soil or green water used for crop and livestock production globally have had no metrics until very recently. The choice of relying on this dataset for assessing water availability in the MENA countries was determined by the inclusion of *all* the water resources available for food production, i.e. not only the usual *blue* water – surface and groundwater – but also *green* – soil – water sources.

The dataset provided by PIK was deployed in this study in order to derive, for each MENA country:

Blue water availability for food production, i.e. the availability of water from surface bodies and aquifers for food production;

Total (green plus blue) water availability for food production, i.e. the availability of water evapo-transpired on cropland and grazing land;

The food-water gap, i.e. the gap between total food-water availability and dietary water requirements;

The degree of food-water scarcity, measured as the percentage ratio between total food-water availability and the water requirements for producing a daily diet of 3,000 kcal per person.

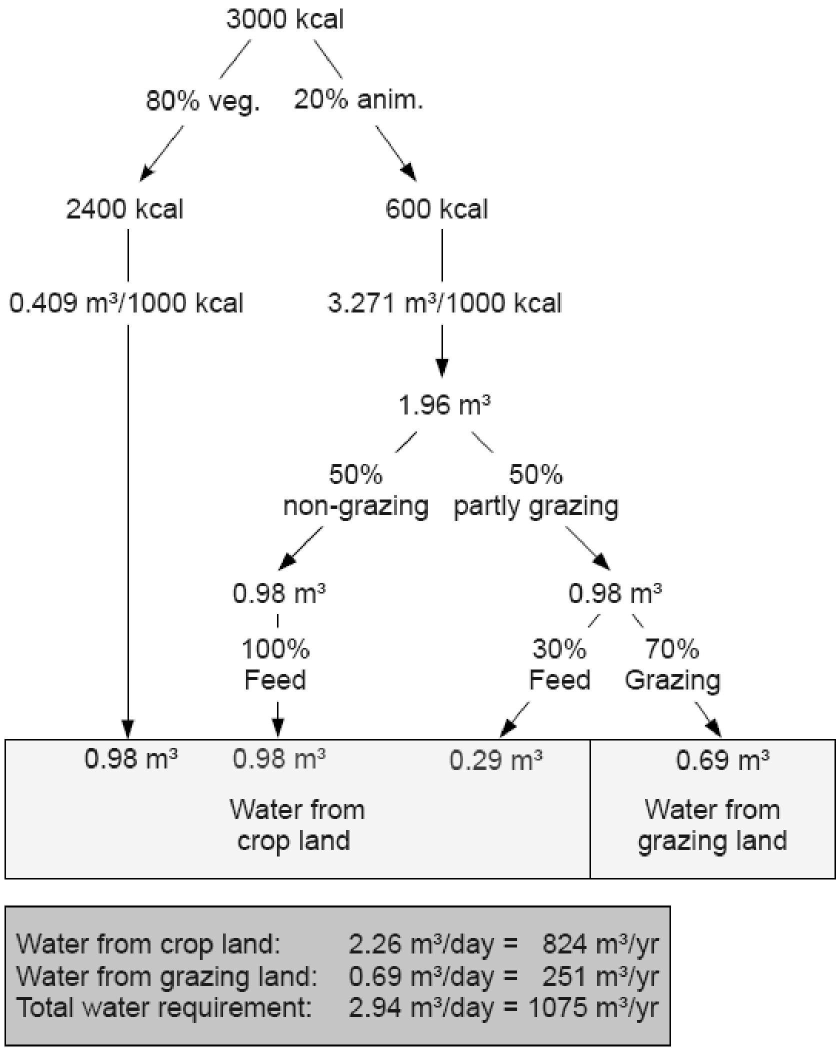
Gerten *et al.* (2011) computed green and blue water availability data through the processed-based, global eco-hydrological model Lund-Potsdam-Jena managed Land. This model considers 9 plant functional types, grazing land and 12 'crop functional types', which represent the world's major food crops. A dataset of cropland distribution around year 2000 was combined with a dataset of maximum monthly irrigated and rainfed harvested areas of 26 crops, then aggregated to 12 (temperate and tropical cereals, rice, maize, pulses, temperate and tropical roots, sunflower, soybean, groundnuts, rapeseed, and a group of "other" crops). Water requirements and water consumption – and thereby crop water productivity – of irrigated and rainfed crop types are distinguished, with an explicit separation of the contribution of green water and blue water on irrigated land. Yields were calibrated for the period around year 2000 against those reported in the FAOSTAT database.

Blue water and green water data were computed assuming that the food produced with these resources is distributed evenly within a country, rather than within individual or groups of grid cells. Blue water resources per country were derived by summing up the runoff computed at the grid level, for all the grid cells in a country. In computing blue water, it was assumed that only 40% of blue water is available for food production, in order to account for both environmental flow requirements and for the variability of the resource in space and time, which often does not match the demand. Industrial and domestic water consumption was not considered, thus overestimating blue water resources where this consumption is significant. Green water resources per country were defined as the water evapotranspired on cropland and grazing land. On rainfed areas it equals total evapotranspiration; on irrigated areas, it equals total evapotranspiration minus evapotranspiration of blue irrigation water. In areas covererd by perennial crops, only half of the water evapotranspired locally was considered, as these crops grow only during part of the year. Rost *et al.* 2008 provided details on how the LPJmL computes green and blue water resource countributions.

The *total green and blue water resource* (m^3 yr-1) was calculated as the sum of the GW and BW resource in a country. Blue water availability, and total green and blue availability were determined by relating the annual BW resource, and respectively, the annual GWBW resource, to a country's population. The assumption behind is that the people living in a given country benefit uniformly from its total water resource, rather than from the resources available in the grid cell where they live. Figure 4.2 illustrates the calculation scheme for water requirements from cropland and grazing land, and LPJmL-computed global values for the individual components (1971-2000 average). For further details on the model, the reader is referred to Gerten *et al.* (2011).

A number of limitations deriving from the use of this dataset must be acknowledged. First, the assessment of blue water availability rests on the assumption that only a fixed fraction of this source of water is available for food production at the regional and country level. Secondly, water scarcity at the subnational scale and in individual years is not accounted for, as water resource availability is expressed as an annual average over a 30-year period. Thirdly, the way income levels affect the demand for food and the composition of the diet is not accounted for. On the contrary, it was assumed that people's diets are based on the same daily calorific amount in all countries and that food commodities are domestically produced only.

Figure 4.2 Calculation scheme for LPJmL-computed global values



Source: Gerten et al. (2011: 889)

4.3.1.2 Water footprint assessment

The study by Mekonnen and Hoekstra (2011a) provided the main source of data deployed to account for the national water footprint of the MENA countries (Chapter 5). As explained in the theory Chapter 3, the water footprint is a multi-dimensional indicator of freshwater appropriation for producing a product or meeting the requirements of a consumer (Hoekstra and Mekonnen 2012). The water footprint of a nation (also referred to as the *water footprint of national consumption*) is defined as the total amount of freshwater that is used to produce the goods and services consumed by the inhabitants of a nation (Hoekstra *et al.* 2011). It accounts not only for the volumes, but also for the source (green, blue, grey) of water used in the different sectors (industrial, agricultural and domestic). The water footprint of a nation has two components: the *internal water footprint*, i.e. the water use inside the country; and the *external water footprint, i.e.* the water resources in the global system accessed via trade. The dependency on water resources from outside the country can be assessed by looking at the ratio between the external component and the total water footprint of national consumption. The characteristics of the water footprint of national consumption in its different components and consumption categories are summarised in Table 4.4.

Table 4.4 Consumption categories and components of the water footprint of national consumption

	Green water	Blue water	Grey water	Internal	External	Dependency ratio
Agricultural products	√	√	√	√	√	√
Industrial products		√	√	√	√	√
Domestic use		√	√			

Source: Author

A country's water footprint of consumption mainly depends on two factors: i) the amount and type of products consumed within the nation; ii) the water footprint of the commodities consumed in the site of production. Due to differences in climate, agricultural management, soil conditions and crop water productivity, the water footprint of agricultural products varies substantially across regions and countries (Hoekstra and Chapagain 2007; Siebert and Döll 2010; Mekonnen and Hoekstra 2010b, 2011; Fader *et al.* 2011; Brauman *et al.* 2013; Finger 2013).

The water footprint indicator has been deployed in this research for two main reasons. First, conventional accounts of water use are restricted to statistics on the withdrawal of freshwater – blue water – resources within a territory, while ignoring the use of soil water (green water) as well as water use for waste assimilation (grey water) (Gleick 2003; FAO 2013). Secondly, conventional water assessments do not consider water use in other countries for producing imported commodities, as well as the water used within the country for producing export commodities. All these aspects are included in water footprint indicators (Hoekstra and Mekonnen 2012). Limitations in the use of this dataset include, first, the lack of data for a number of countries in the region, namely, Bahrain, Oman, Qatar and Iraq. Secondly, the use of 10-year averages does not enable consideration of the temporal evolution of water footprints in the countries of interest.

4.3.1.3 Virtual water 'flows' assessment

The datasets deployed for the assessment of virtual water 'flows' at the global level and for the MENA countries (Chapter 6 and 7) are based on the studies by Tamea *et al*. (2013) and Carr *et al.* (2013). The author has collected the dataset described in this sub-section from the Polytechnic University of Turin mainly in the year 2013.

These studies reconstructed the patterns of global agricultural commodity trade for 309 products, which were internationally traded during the period 1986-2010, using the data provided by the Food and Agricultural Organization of the United Nations Statistics Division (FAOSTAT). FAO data reported the volumes produced and traded in any given country for each product and year considered[13]. Data collected from FAOSTAT consist of detailed international trade of 309 agricultural commodities exchanged globally during the period 1986-2010. Traded volumes for each product in any given year and country are those reported by the world's exporting economies and have been rectified to political changes over the 25-years period to allow comparison among different years. Political rectification is detailed in Carr *et al.* (2013).

[13] The detailed food and agriculture trade data collected, processed and disseminated by FAO comply to the standard International Merchandise Trade Statistics Methodology, and are mainly provided by national authorities and other international organizations. For further details on the International Merchandise Trade Statistics Methodology, the reader is referred to UNDESA (1998).

The 309 agricultural commodities analysed here (listed in the Appendix A) include those having an available estimate of the country-specific *virtual water content* from the recent assessment by Mekonnen and Hoekstra (2010b). This study was deployed in order to convert the volumes of traded commodities into virtual water equivalents. The 'virtual water content' of a product is the volume of water consumed or polluted in the production process (Hoekstra *et al.* 2011). It measures the volume of water needed to produce the commodity in a given country[14]. The study by Mekonnen and Hoekstra (2010b) provides virtual water contents averaged over the years 1996-2005, based on a distributed model of daily soil water balance forced by hydrological inputs, which expresses evapotranspiration from cultivated areas and the associated agricultural yields. Country-specific estimates result from the spatial average over the cultivated areas of the country. These estimates do not take into account possible variations in virtual water contents of crops due to changes in efficiency, technology improvements or climate variability, which affect the water requirement of crops. However, these features are indirectly expressed by the inter-annual change of traded goods, which reflect modifications of agricultural production (such as, reductions in export during severe droughts or constant increments due to technological advances).

Virtual water 'trade' between nations has been computed by multiplying trade flows by their virtual water contents, consistent with Hoekstra *et al.* (2011). The methodology deployed a widely established approach to compute virtual water 'flows' (among others, Carr *et al.* 2013; Hoekstra and Mekonnen, 2012). A limitation must be acknowledged here. While some countries report the final destination country of their exports, others report only the first destination country. Re-exports is thus not explicitly accounted for. This limitation may have affected the assessment of virtual water 'exports' in the countries where re-

[14] It is noteworthy to say that virtual water contents differ from water footprints because the former refers "to the water volume embodied in the product alone", whereas the latter "refers not only to the volume, but also to the sort of water that was used (green, blue, grey) and to when and where the water was used" (Hoekstra *et al.* 2011: 46). The water footprint of a product is a multidimensional indicator, whereas the 'virtual-water content' or 'embedded water' refer to a volume alone.

exports account for a significant share of total commodity exports, bringing about an over-estimation. This is the case of the UAE, the third major commercial hub in the world in 2010, with a re-export to total export ratio of 25% (UNSD 2014). This limitation affects all virtual water studies based on FAO trade data, as pointed out by Konar *et al.* (2012). Limitations in the available data also concerned exports in agricultural commodities over the period considered. The assessment of virtual water 'trade' in Iraq was affected by the fact that the country reported no exports of agricultural products over the period considered (1986-2010).

The analysis presented in Chapter 6 refers to the sum of green (soil water) and blue virtual water 'flows' resources (i.e. originating from surface and groundwater); whereas, in the analytical Chapter 7, the two sources 'embedded' in the MENA virtual water 'trade' are differentiated. The water polluted in the production process – often referred to, as *grey water* – was not considered because of the uncertainties inherent in its determination and its minor role in agricultural production compared with green and blue water.

Virtual water 'trade' data were also subdivided into four primary groupings: edible vegetal-based products (such as cereals, fruits and vegetables), hereby referred to as *crops*; edible animal-based products (such as meat and dairy), here referred to as *animal products*; high-value food commodities (such as sugars, coffee and chocolate), hereby referred to as *lux-foods*; and non-edible commodities (such as plant fibres, oils, oil cakes or animal hides), hereby referred to as *non edible*. Table 4.5 summarises the main commodities included in the four categories of agricultural products. The full list is provided in the Appendix A.

Table 4.5 Categories of agricultural commodities considered in virtual water 'flows' analyses

	Description
Crops	Cereals, fruits and vegetables
Animal products	Live animals, meat and diary
Lux-foods	Sugars, coffee and tea, chocolate, spices, alcoholic

	beverages
Non edible	Plant fibres, non-edible oils, oil cakes, animal hides, tobacco

Source: Author

Data describing the production of agricultural commodities in each country and each year in the 25-years span are also considered as calculated by Tamea *et al.* (2013). They result from multiplying the production volumes given by FAOSTAT by the corresponding country-specific virtual water contents. By summing up all the agricultural commodities produced within a country in a given year – excluding double counting of secondary products – over their virtual water contents, the water footprint of agricultural production was obtained.

Assuming negligible stock variations and minimal waste components, it is possible to "close" the virtual water 'balance' by equating all the virtual water inputs and outputs in a given area or country. The relationship among the four components of the virtual water 'balance' is the following: the sum of the water footprint of production, P (i.e. the water used to produce agricultural commodities in the area), and virtual water 'imports', I, equals the water footprint of consumption, C (i.e. the virtual water associated to the consumption of agricultural commodities in the area), plus virtual water 'exports', E. That is:

$$P + I = C + E$$

By summing up the virtual water 'balances' of all MENA countries in each year, the virtual water 'balance' for the aggregated MENA countries was generated. Building on this relationship and assuming negligible stock variations and waste levels, the water footprint of national consumption of agricultural products of the MENA countries in the period considered was computed as follows:

$$C = P + I - E$$

Finally, the dependency of the MENA countries from external water resources to secure their food needs will be evaluated by deploying a *virtual food-water* *'import' dependency indicator* (D). Consistently with Hoekstra *et al.* (2011), this indicator can be defined as the ratio between the external to the total water footprint of national consumption of a given country, that is:

$$D = WF_{cons,\ nat,\ ext} / WF_{cons,\ nat}$$

WF_c is calculated from the virtual water balance of each country (Import – Export + WF_p) where WF_p is the water footprint of agricultural production obtained from converting into virtual water volumes the agricultural production by commodity provided by FAOSTAT, as detailed in Tamea *et al.* (2013). Virtual water import dependency will be assessed in the MENA countries, averaged over the period 1986-2010.

Since the dataset deployed does not enable commodities tracking, it is not possible to quantify the fraction of virtual water 'exports' that actually results from the re-export of imported goods (and virtual water). However, the range of variability of *D* can be identified by considering the two extremes cases in which: i) all imported goods are consumed within the country and there is *no* re-export at all (*reE*=0). In this case the value of *D* will be maximum ii) local consumption is met by internal production only, and the whole export is a re-export of imported goods (*reE*=*E*), identifying the minimum value of *D*. If the numerator becomes negative, a zero value is taken instead (but in the presented case it never happens). Thanks to the small export fluxes of a number of MENA countries, this range of values is limited and allows taking intermediate values as reference for the following considerations. This range of minimum-maximum values has calculated in Chapter 6, aiming at increasing understanding on the virtual water 'import' dependency of the MENA countries. Limitations in the available data did not enable us to account for national water footprints based on local water resource productivities over time. It is here argued however that temporal variations of agricultural yields or climatic conditions reflect into different values of agricultural production from year to year provided by FASTAT data.

Per capita values of virtual water 'trade' and production are based on population data from FAOSTAT (2013), which refer to the "World Population Prospects: The 2012 Revision" by the United Nations Population Division.

4.3.1.4 Green and blue virtual water 'flows' assessment

The studies by Tamea *et al*. (2013) and Carr *et al.* (2013) also provide the main datasets deployed for the assessment of green and blue virtual water 'flows' at the global level and for the MENA countries, which is the specific focus of Chapter 7. The reliance on the very same sources for assessing virtual water 'trade' (both in Chapter 6 and 7) is a major strength of the study in that it has made the analysis on virtual water 'trade' consistent throughout. The current available studies on virtual water 'trade' and water footprints differ in fact not only in terms of the sources of data deployed for assessing international commodity trade flows (e.g. FAO or UNSD data), but also in terms of the period considered (not only the selection of years, but also whether to consider averages or temporal dynamics), the number and types of traded commodities (e.g. agricultural only, or agricultural and industrial), as well as their categorisation.

The period considered in the assessment of green and blue virtual water 'flows', presented in Chapter 7, is 1986-2010. The products analysed include crops (such as cereals, fruits and vegetables), animal products (such as meat and dairy), lux-foods (such as sugars, coffee, alcoholic beverages and spices), and non-edible agricultural commodities (such as plant fibres, oils, oil cakes or animal hides).

With respect to the Tamea *et al.* (2013) and Carr *et al.* (2013) studies, two main methodological innovations are introduced here. First, the FAO trade data deployed for the assessment of virtual water 'flows' over the period analysed are those reported by the world's exporting economies rather than the maximum reported by importers and exporters. Secondly, the two studies did not differentiate the two sources of virtual water 'embedded' in global virtual water 'trade', as pursued here, but rather considered the sum of the two sources (i.e. *total* virtual water 'flows'). The proportion of green and blue virtual water ‘embedded’ in traded commodities have been assessed on the basis of the green and blue water footprint estimates provided by Mekonnen and Hoekstra (2011a). These estimates are country and product-specific and provide the only available datasets so far.

4.3.1.5 Water scarcity in the MENA virtual water ‘trade’ partners

Water scarcity assessments in the MENA countries as well as in its virtual water ‘trade’ partners are based on the study by Gerten *et al.* (2011), which, as detailed in Chapter 5, estimates water scarcity by including both green and blue water resource availability for food production in a given country. FAO metrics on water resource availability do not include green water resources and can thus only partially depict water resource availability not only globally but also in the MENA.

4.3.1.6 Blue water scarcity of river basins in the MENA virtual water ‘trade’ partners

Blue water scarcity in the MENA virtual water ‘trade’ partners is based on the assessment of blue water scarcity of the world’s river basins, over the period 1996-2005, provided by Hoekstra and Mekonnen (2011: 10). Blue water scarcity is defined as the ratio of a river basin’s blue water footprint to blue water availability (natural runoff minus environmental flow requirements). All variables are estimated on a monthly basis rather than on an annual scale as blue water scarcity varies not only from year to year but also within the year. Environmental flow requirements have been established on a “precautionary” fashion, i.e. allocating 80% of natural run-off to environmental flow requirements and 20% to human use. The study by Hoekstra and Mekonnen (2011) is deployed in the chapter in order to understand the potential impact of virtual water ‘trade’ on water resources in the countries that ‘export’ (blue) virtual water to the MENA.

Blue water scarcity values are classified into four levels, in three of which environmental flow requirements are not met:

Low blue water scarcity (<100%): it occurs when the blue water footprint in the river basin is lower than 20% of natural runoff and does not exceed blue water availability. In this case, river runoff is unmodified or slightly modified, and environmental flow requirements are not violated.

Moderate blue water scarcity (100-150%): it occurs when the river basin's blue water footprint is between 20 and 30% of natural runoff, which is, as result, moderately modified. Environmental flow requirements are not met.

Significant blue water scarcity (150-200%): it occurs when the river basin's blue water footprint is between 30 and 40% of natural runoff, which is, as result, significantly modified. Environmental flow requirements are not met.

Severe blue water scarcity (>200%): it occurs when the river basin's monthly blue water footprint exceeds 40% of natural runoff, which is, as a result, seriously modified. Environmental flow requirements are strongly violated.

4.3.1.7 Socio-economic adaptiveness

The study deploys the Human Development Index (HDI) as an indicator of the socio-economic adaptiveness of the MENA economies. As detailed in the theoretical background of the study, the theory of *social adaptive capacity* informs the present study and is deployed in order to shed light on the extent to which second-order resource availability enables countries to effectively cope with first-order resource deficits (Ohlsson 1999; Turton 1999; Ohlsson and Turton 1999; Turton 2000).

In the first Human Development Report, released by the United Nations Development Programme (UNDP) in 1990, three basic dimensions of human development were combined into a unique and composite development index, which became a reference for both social and economic development. The use of this index is also useful in that it enables comparisons both between and within countries to be made. The dimensions considered in the HDI are (UNDP 2013):

- **Health conditions**, measured as life expectancy at birth.
- **Education conditions**, measured as mean years of schooling for adults aged 25 years and expected years of schooling for children of school entering age;
- **Standard of living**, measured as a country's Gross National Income per capita (PPP $)[15].

For each dimension, a minimum and maximum value is set (the so called *goalposts*) and is measured as a value between 0 and 1. The scores for the three HDI dimension indices are then aggregated into a composite index using geometric mean.

The HDI is used in the study as an alternative to GDP and GNI for measuring socio-economic development as it captures aspects of human development that are neglected when considering only the wealth conditions of a country. The link between economic growth and human development is in fact "not automatic" (UNDP 1990: 3).

4.3.1.8 Trade data

The trade data presented in the analytical chapters of the study rely on three main sources. Data from FAOSTAT (2013) are deployed in order to ensure consistency with the assessment of virtual water 'trade' based on Tamea *et al.* (2013) and Carr *et al.* (2013). FAO data on commodity trade were used with regards to data on production, import and export of agricultural commodities. United Nations Statistical Division's data (UNSD 2014) are also deployed in order to understand the extent to which commodity (and virtual water) exports are actually *re-exports*

[15] It is noteworthy to say that the decent standard of living component is measured by GNI per capita (PPP$) instead of Gross Domestic Product per capita (PPP$) The HDI uses the logarithm of income, to reflect the diminishing importance of income with increasing GNI.

of imported products. It is particularly important to consider this aspect, as a number of MENA countries are commercial hubs. Highlighting the proportion of re-exported goods in total exports enabled us to understand the extent to which virtual water 'exports' data (based on FAOSTAT 2013) might have been over-estimated for a few countries in the region. Trade data by the United States Department of Agriculture (USDA 2013) were finally deployed when comparing (and/or ranking) the level of imports and exports of the different world's economies.

4.3.2 Qualitative secondary data sources

Document analysis related to water and food security in the Middle East and North Africa has been an important method used in the study. A significant number of studies on the region's water-related challenges has been published as *grey literature*, which includes government documents, non-profit and think-thank reports, consultancy firm assessments, project websites and other types of online documentation etc. Secondary data has also been accessed through conventional *academic sources*, such as books and peer-review articles. Secondary sources included qualitative research studies on the MENA political economy, political geography, economic growth and development; commodity trade; water scarcity and other environmental concerns. The use of *media articles and videos* has also been useful in identifying water-related policy narratives in the MENA countries.

4.4 Limitations of the study

Some of the limitations of the analysis developed in this thesis have been addressed in the previous Sections of this chapter. The study also presents other limitations that need to be acknowledged, the first of which is related to the geographical scope of the research. The MENA region is in fact very diverse and heterogeneous from a biophysical, economic and social point of view. The classification adopted in this study includes the region's developing economies (as defined by the World Bank, except Djibouti) and the more diversified economies of Israel, Turkey and the GCC countries.

A second limitation derives from the time boundaries of the research. The study addresses the extent to which the MENA countries rely on virtual water 'trade' to secure their food-related water needs by looking at trade in agricultural goods over the past two and half decades (1986-2010), despite the region's countries run out of water in the 1970s (Allan 2001). This limitation was mainly due to data availability, quality and quantity. It is acknowledged that these limitations reflect into the precision of data analysis. One example relates to the water scarcity assessment provided in Chapter 5. Water scarcity in the MENA economies is assessed by relying on long-term annual averages, thus masking water scarcity at sub-national scale and in specific years or seasons. Another limitation is the lack of consideration of water quality issue in the MENA countries.

The study's limitations also concern data availability on trade in agricultural goods, which affected the assessment of virtual water 'trade' in the MENA. For instance, the assessment of virtual water 'trade' in Iraq was affected by the fact that the country reported no exports of agricultural products over the period considered (1986-2010). Triangulation has been applied rigorously to the data collection to reduce any bias or drawbacks in the data.

Last but not least, the highly volatile political developments related to the so called "Arab Spring", which affected food and water policy in the region have not been explicitly addressed. When the research commended in September 2009 the MENA region has in fact a dramatically different political landscape. The overall limitations of the study will be discussed in Chapter 8, as well as the pathways for future research.

4.5 Research ethics

As the present study is based on further re-analysis of pre-existing data, ethical approval was not required in accordance with the rules and procedures set by King's College London, University of London. Further information can be found

here:
http://www.kcl.ac.uk/innovation/research/support/ethics/training/existingdata.aspx.

4.6 Conclusions

This chapter has reviewed the methodology and methods of the study. The methodological approach of the research has been defined as *mixed*, as it combines and integrates elements of both quantitative and qualitative approaches. The chapter has also explained the evolution of the research process in the different phases, and highlighted their inductive and deductive reasoning phases. Finally, the sources of data deployed in the study have been presented and their limitations highlighted.

The next three chapters will address the three subsidiary questions of the study. More specifically, chapter 5 will provide an assessment of food-water resource availability in the MENA region, addressing the first subsidiary question of the study (that is, *"To what extent can local water resources meet the food-water requirements of the MENA political economies?"*).

Chapter 6 will investigate the extent to which the MENA political economies depend on virtual water 'imports' to secure their population's food needs, answering the second subsidiary question of the study (i.e. "*What has been the role of international trade in meeting the water requirements of the MENA economies?* And, more specifically: *To what extent have the MENA countries relied on virtual water 'trade' to secure their food-water needs?"*).

Chapter 7 will identify and analyse the sources of water 'embedded' in the MENA virtual water 'trade' in order to discuss the role and significance of international agricultural trade, which entails an invisible 'exchange' of water resources at the global level. This chapter will answer the third subsidiary question of the study (*To what extent have green and blue water resources underpinned the MENA virtual water 'trade'?*).

5. Food-water scarcity in the Middle East and North African region

5.1 Introduction

The overarching aim of this chapter is to investigate the relationship between water and food security in the MENA region by showing the extent to which the MENA political economies can meet their water requirements for food production through local water resources. Water security and food security are inextricably linked, as agriculture uses more water than any other human activity. Food production accounts for about 90% of the water needed by an individual or an economy. This water is referred to as *food water*, (Allan 2013a; 2013b) and can be either soil (green) water or surface and groundwater (blue water). The water needed for industrial and domestic use (*non-food water*), instead, accounts for only 10% of society's water needs and is always blue water sourced (Allan 2013a; 2013b).

This chapter will seek to increase understanding of the MENA water challenge by providing an assessment of food-water availability in the region's political economies. The assessment is original in that it will include the *full* water resources available for food production. These resources include not only the usual blue water available for irrigation, but also green water resources, which support rainfed crop production. The analysis will show that, although they have been ignored until very recently, green water resources play a fundamental role in underpinning food production globally and in the MENA region. Food-water availability will be assessed by relating the MENA countries' water requirements to produce a targeted diet of 3000 kcal per capita per day, considered as a benchmark for hunger alleviation, with the available water resources.

5.1.1 Research questions and hypotheses

This chapter is concerned with the first subsidiary research question of the study, that is: ***To what extent can local water resources meet the food-water requirements of the MENA political economies?*** Two sub-questions have been identified.

Sub-question 1.1 *To what extent is the MENA region facing a water challenge?*

Hypothesis. The first sub-question of this chapter has been extensively addressed in Chapter 2 (Background), which has presented and analysed the main environmental, economic and political issues that make the MENA water question particularly urgent. These challenges are not only related to the region's poor water endowments, but also to the combination of a number of factors that are driving, and will in the future, increased pressure on water resources. It has been shown that these challenges are mainly the growth in population observed in the bulk of the region's political economies, combined with urbanisation; changing lifestyles and dietary habits - with an increase in the consumption of water-intensive foodstuffs, such as animal products; the diversification of the economies, which is accompanied with an increase in the industrial demand for water; and finally, the expected changes in precipitation, evapotranspiration and temperature due to climate change. All these factors will drive a major increase in water demands, and thus call for a rethinking of the region's water resource management and policy in a more sustainable way.

Chapter 2 has also identified the nature of the region's political economies and how they have addressed water deficits, and highlighted what hinders the promotion of sound water reforms in the water sector. The chapter showed that, although the region entered water stress in the 1970s, this important predicament, which is both water resource and economic significant, has been strategically de-emphasised by local governments and policy-makers, who prefer to maintain the *status quo*. Some of the problems with the *status quo* namely that Water resources are, in fact, seriously (over)allocated to low-value uses - mainly to irrigated agriculture, and ineffective water resource management is a serious problem in many countries in the region. The chapter also argues that MENA policy-makers are locked in a 'sanctioned discourse', which fundamentally determines the extent to which water policy reforms can be proposed and achieved. These hypotheses have been corroborated in Chapter 2. The analysis developed in the background chapter of this study frames and underpins this analytical chapter. A brief review of these issues is provided in Section 5.2 of this chapter.

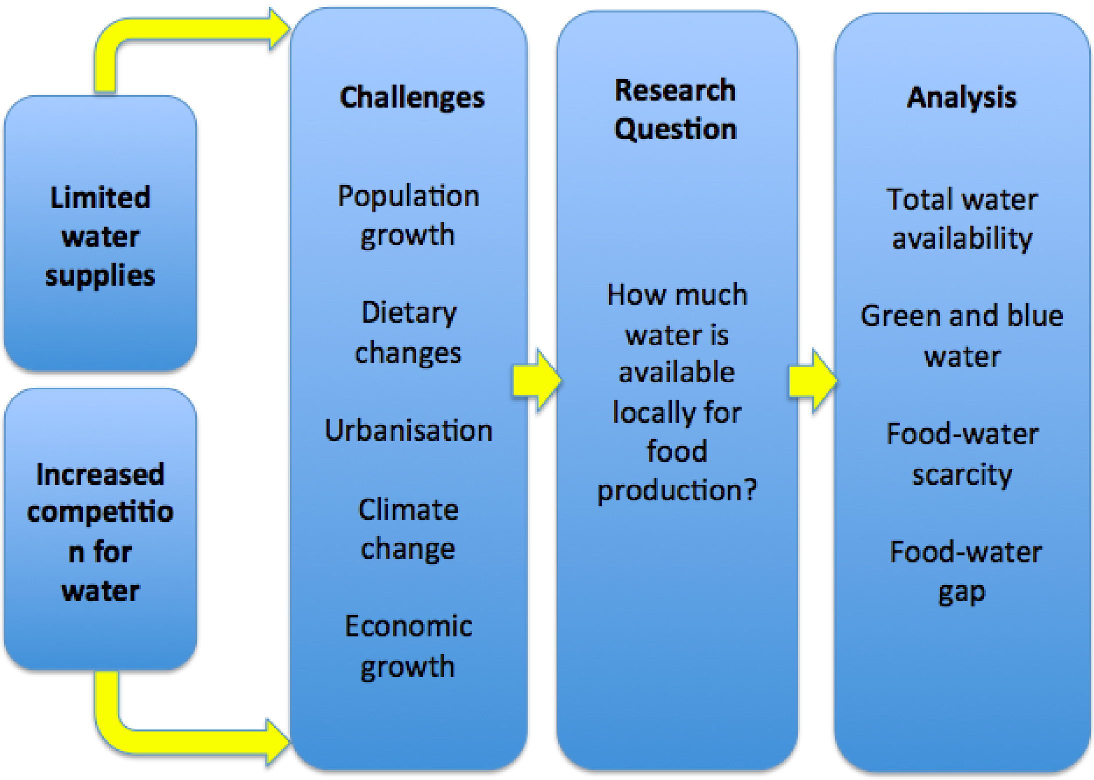
Sub-question 1.2 *How is the MENA region endowed with food-water resources? To what extent can local water resources meet the region's requirements for food production?*

Hypothesis. It is hypothesised that the region's political economies *cannot* meet the food-water needs of their populations with their local water resource endowments, as these are insufficient to produce a specific targeted dietary intake, considered as a benchmark for food security. This hypothesis will be tested by, first, assessing total water availability for food production in the region's political economies by including not only surface and groundwater resources, but also the water stored in the root zone. By comparing *blue water availability* with *total* (*green plus blue) water availability* for food production, it will be shown that green water resources represent a substantial and rising deficit in food water in most of the region's economies. The chapter will argue that there is much potential to reduce the region's food-water gap by unlocking the potential of this source of water.

Secondly, in order to investigate the extent to which the MENA countries can meet the requirements for food production of their populations, the study will deploy a water scarcity indicator relating the MENA countries' capacity to produce a balanced diet of 3000 kcal per capita per day, here assumed to consist of 80% vegetal and 20% animal-based products, with local green and blue water resources. It will show that there is an imbalance between the requirements to produce the targeted diet and local availability of water resources in most of the

MENA political economies, although to different extents. The *food-water gap per country* will finally be assessed. The study will therefore advance knowledge on the MENA water scarcity problems not only by investigating the relationship between food needs and water resource availability; but also by providing an assessment of its *full* water availability for agricultural production. An overview of the issues explored in this chapter is provided in Figure 5.1.

Figure 5.1 Overview of this chapter



Source: Author

5.1.2 Structure

The structure of the chapter is divided into four main sections. The first section has presented the objectives, research questions and hypotheses of this chapter.

The second section reviews the main environmental, economic and political challenges that make the MENA water question particularly urgent (sub-question 1). The third section provides an assessment of water availability for food production, by distinguishing between the different sources of agricultural water in the region's countries, and identifies the region's food-water gap (sub-question 2). The chapter concludes with a summary of the main findings.

5.2 The scope of the MENA water challenge

The aim of this section is to review the key determinants and driving forces of water scarcity in the MENA region. These issues have been presented and analysed in detail in the background chapter of this study (Chapter 2). The first sub-question of this chapter to be addressed is:

To what extent is the MENA region facing a water challenge?

The MENA region is acknowledged as being one of the most water-scarce regions in the world (Gleick 2000; Roudi-Fahimi *et al.* 2002; World Bank 2009b). Per capita freshwater availability has decreased from 4,000 m^3/year in 1950 to 1,100 m^3/year in 2007 (World Bank 2007). Absolute and per inhabitant blue water resources in the Middle East are the lowest in the world (FAO 2003a). Renewable water resource withdrawal in the region already exceeds the critical thresholds of 20 and 40%, and water tables are declining as farmers and cities abstract water above rates of replenishment from recharge and aquifer leakage (FAO 2011). Since the 1970s, the water demands of its political economies have exceeded the capacity of the local resource base for food self-sufficiency (Allan 1997b). In the MENA there is "virtually no more freshwater to develop" (FAO 2000: 50).

Despite it being one of the major environmental challenges currently facing the MENA region, water scarcity is rarely taken into consideration when formulating economic policies in the region (Sakmar *et al.* 2011). According to recent studies, the situation will worsen. Based on climate change projections, two thirds of the region's economies will have less than 200 m^3 per capita by 2040-2050. Unmet water demand for the whole MENA region will also increase from 16% currently to 37% in 2020-2030 and 51% in 2040-2050 (Immerzeel *et al.* 2011). The development of integrated hydrological and economic information on water resources for policy and decision-makers has been recognised as a crucial step if more sustainable water management is to be installed in the region. This situation was observed by the United Nations Economic and Social Commission for Western Asia (Sakmar *et al.* 2011).

Four main factors that have been identified as the main *driving forces* of the increase in demand for freshwater in the region. These driving forces are the key factors, trends or processes influencing the situation and status of the MENA water resources. A first driving force is the dramatic increase in population, as it will also drive an increase in food demands. Population in the MENA region has quadrupled during the second half of the 20th century and is the second fastest growing population in the world (Roudi-Fahimi and Mederios Kent 2007). Urbanisation is also a driving force that will impact future water choices in the MENA region, as most of population growth has occurred in urban areas (Tropp and Jägerskog 2006).

Secondly, additional water demands have been associated with rising standards of living, industrial activity and energy demands. Third, expected impacts of climate change on the region's water resources and agricultural land, which will not only affect the agricultural sector due to changes in precipitation, temperature, stream flows and evapotranspiration, but also the function and operation of existing infrastructures, such as, hydropower, drainage and irrigation systems etc. (IPCC 2008). Fourth, dietary shifts towards a higher calorific intake of (water-intensive) animal-based products[16]. The MENA is a large importer of sheep meat, poultry and beef (OECD-FAO 2011), and is expected to lead a substantial growth in global poultry imports in the next future (OECD-FAO 2013).

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[16] It is noteworthy to say that the extent to which livestock industry and meat consumption impact water resources is determined by meat production systems, which are very heterogeneous both in farm practice and in geography (Steinfeld *et al.* 2010; Thorton and Herrero 2010). As highlighted by Ridoutt *et al.* (2012), the variability between different meat production systems should be taken into account in any discussion about the role of livestock products in sustainable food systems.

While these forces have driven an increased water demand, which may exacerbate the MENA physical water resource scarcity, the reasons for water problems lie, however, in the capacity of agricultural sectors, local governments and international institutions to respond and adapt to the region's resource scarcity (Allan 2001). The water scarcity predicament of the MENA region has been compounded by large-scale water management problems, such as over-exploitation of aquifers, deteriorating water quality, and rationed water supply and sub-optimal irrigation services (World Bank 2007). These problems also have negative impacts on human health, the productivity of agriculture and water ecosystem services (Immerzeel *et al.* 2011).

The focus of this study is on *food-water*, that is, the water employed for food production Agriculture is the most water-intensive activity in society and by far the biggest water user in the MENA region. Water consumption by households and industry in the region is relatively small in most of the region's economies compared with allocations to irrigated agriculture despite the poor returns to water in irrigated farming (Richards and Waterbury 2008). Agricultural water use is over 85% of total water use in many of the region's economies (FAO 2012) and is mainly allocated to irrigated cereals despite the low returns generated per cubic meter. It is a tenth of what would be achieved by growing higher-value crops, such as vegetables (World Bank 2008). Irrigated cereal area covers 9.5 million ha and annual production is 34.9 million metric tons (Rosegrant *et al.* 2002). The highest irrigation potential in the region can be found in Turkey, Iran and Iraq (FAO 2013). Irrigation systems are mainly dependent on groundwater resources, as well as in India, China, central USA, and Australia (FAO 2011). Declining aquifer levels and extraction of non-renewable groundwater thus present a growing risk to food production systems in the region.

Current and future tensions in the MENA region will be a consequence of the availability of water for food production. Arable land is also a further constraint to food production in the region. Some of the MENA economies - such as, Qatar, UAE, Bahrain and Kuwait - also have the lowest arable land per capita in the world (FAO 2013). All the MENA countries are large net importers of agricultural products, such as cereals, sugar, cooking oil and other food commodities (World Bank 2003).

The region's countries already make up the water deficit through international food trade. The import of food is also an 'import' of the water 'embedded' in the traded commodities (Allan 2001). This implicit 'trade' in water meets more than half of the total water needs of many of the region's economies, such as Bahrain, Israel, Jordan, Kuwait, Oman, and West Bank and Gaza (World Bank 2007). This mechanism has provided the MENA countries with food-water security for the past few decades (Allan 2001; 2002a; 2002b) and has been enabled by a long-run downward trend in prices of food commodities (Rosegrant *et al.* 2001). The extent to which the MENA economies rely on virtual water 'trade' to secure their food needs will be the focus of the following analytical chapters of the study (Chapter 6 and 7).

5.3 The water and food security nexus

The aim of this chapter is to increase understanding on the relationship between water and food security in the MENA region, by investigating the extent to which the region's countries are faced water scarcity *vis-à-vis* their population's requirements for food production. Sections 5.3 and 5.4 will seek to answer the second subsidiary question of this chapter, that is:

How is the MENA region endowed with food-water resources? To what extent can local water resources meet the region's requirements for food production?

In order to answer these questions, this chapter will provide an assessment of food-water scarcity in the MENA political economies. The assessment is original in that it includes the *full* water resources available for food production. These resources include not only the water contained in aquifers and surface bodies (blue water), i.e. the sources of irrigated agriculture, but also soil (green) water resources, which underpin rainfed agriculture. Green water is here defined as the water evapotranspired on cropland and grazing land in a country. On rainfed areas it equals total evapotranspiration; on irrigated areas, it equals total evapotranspiration minus evapotranspiration of blue irrigation water (Gerten *et al.* 2011). Despite green water being identified by Falkenmark in the early 1990s, the fundamental role it plays in underpinning water and food security globally has been ignored until very recently. It is argued in this study that *both* green and blue water resources need to be included in water scarcity analyses, as they are both sources of food-water. By doing so, the study aims to overcome a major limitation of traditional water scarcity assessments. The study also argues that incorporating the concept of green water can much better inform effective water resources planning in the region.

In order to account for the *total* food-water resources available in the MENA political economies, the study will deploy the "enhanced" water scarcity indicator, which has recently been introduced by the Potsdam Institute for Climate Impact Research. This water scarcity indicator relates the availability of water resources for agriculture in a country with the water requirements to produce a targeted diet, based on local crop water productivity, in order to show countries' capacity to feed their populations. By deploying this indicator, this study will assess the food-water gap of the different MENA economies. More details on the data sources of this chapter are provided in the Methodology chapter.

5.4 Assessing food-water scarcity in the MENA

This section provides an assessment of food-water scarcity in the MENA, which is aimed to understand the extent to which local water resources are sufficient to meet the requirements for food production in the region's economies. First, total water resource availability for food production (referred to as *total food-water availability* per country) will be assessed and compared with blue water availability. Food-water availability includes the *full* water resource available for food production, i.e. blue and green water resources, and will therefore provide a measure of the *actual* volumes available for food production in the countries under investigation. Secondly, green and blue water resource shares will be differentiated.

Thirdly, *total food-water availability* per country will be related to the water requirements for producing a balanced diet of 3000 kcal per person per day, assumed to consist of 80% vegetal and 20% animal-based products, based on local crop water productivity. Finally, the *degree of food-water scarcity* of each MENA country will be assessed. It will be shown that the scope of the food-water gap varies among countries not only according to their individual total food-water availability but also based on their crop water productivity, which determines the volume of water that is required to produce the targeted diet. The global water scarcity assessment developed by Gerten *et al.* (2011) through the global eco-hydrological model Lund-Potsdam-Jena managed Land (LPJmL), provided the main source of data of the analysis that follows. More details on the LPJmL model have been provided in the methodology Chapter 4 of the study. Table 5.1 provides some essential definitions of the terms used in this section.

Table 5.1 Essential definitions

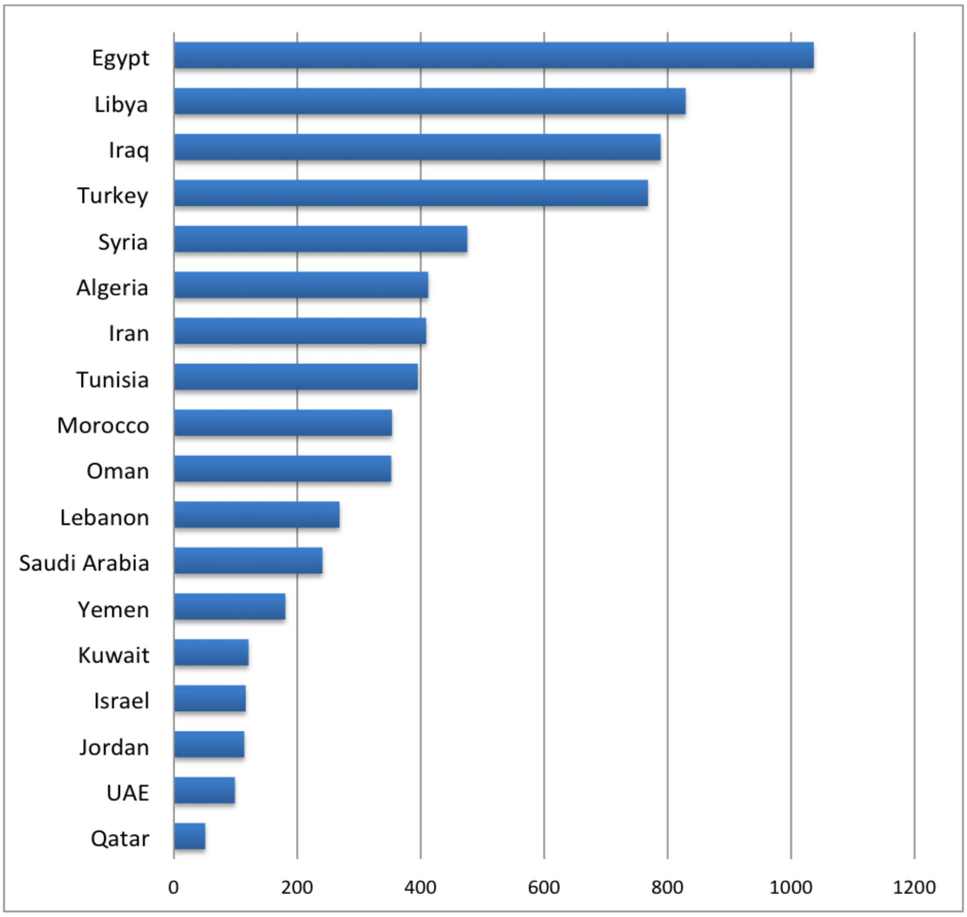
Terms	Description
Blue water availability	Availability of water from surface bodies and aquifers for food production
Green water availability	Availability of water evapotranspired on cropland and grazing land
Total food-water availability	Full water resources available for food production. It is the sum of green and blue water resources
Water requirements	Requirements for producing a targeted diet of 3,000 kcal per person per day
Food-water gap	Gap between total food-water availability and dietary water requirements
Degree of food-water scarcity	Percentage ratio between total food-water availability and the water requirements for producing a daily diet of 3,000 kcal per person

Source: Author

5.4.1 Blue water availability VS total water availability

Figure 5.2 and 5.3 show, respectively, the annual country-scale availability of blue water per capita and the annual country-scale availability of green water per capita in the MENA economies. All values are averaged for the period 1971-2000. Blue water availability is very low in the region: 14 out of 18 countries have less than 500 m^3 per person per year. Egypt, Libya, Iraq and Turkey are exceptions, with a per capita blue water availability ranging from about 750 m^3 per year to over 1000 m^3 per year. Syria, Algeria, Iran, Tunisia, Morocco, Oman, Lebanon and Saudi Arabia have an annual availability ranging between 200 and 500 m^3 per person. The lowest levels are observed in Yemen, Kuwait, Israel, Jordan, UAE and Qatar, where blue water resources are less than 200 m^3 per person per year.

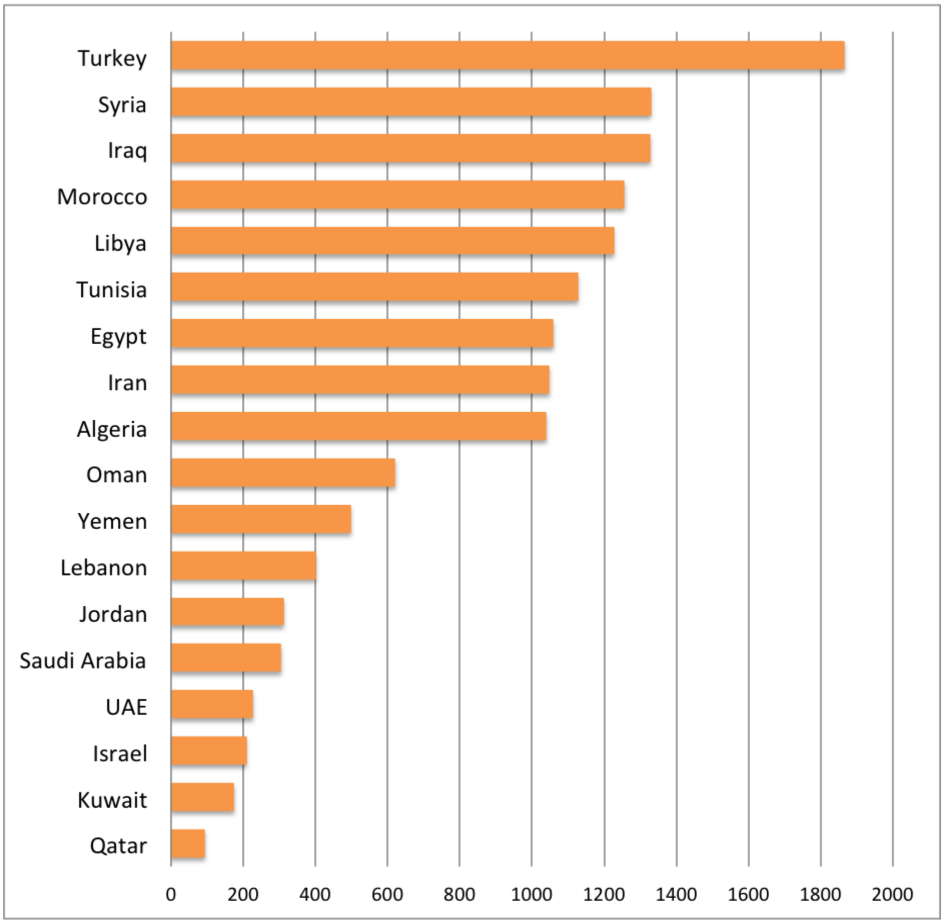
Figure 5.2 Blue water availability per country (m^3 cap^{-1} $year^{-1}$, averaged over the period 1971-2000)



Source: Elaboration based on Gerten et al. 2011

By adding green water resources, water availability becomes significantly higher in most of the region's countries. The percentage increase in water availability is over 100% in 9 out of 18 countries. Turkey is the most water-abundant economy in the MENA region, with a total - green plus blue - water availability per capita that exceeds 1,850 m^3 per year. Green water ranges between about 1,300 and 1,000 m^3 in Syria, Iraq, Morocco, Libya, Tunisia, Egypt, Iran and Algeria, and is about 600 m^3 in Oman. Yemen, Lebanon, Jordan and Saudi Arabia have between 250 and 500 m^3 of food-water per person per year. Finally, UAE, Israel, Kuwait and Qatar have less than 250 m^3 per person per year. All the MENA countries, with the exception of Turkey have less than 1,700 m^3 per person per year. Table 5.2 and 5.3 summarise the main findings of this section.

Figure 5.3 Total food-water availability per country (m^3 cap^{-1} year^{-1}, averaged over the period 1971-2000)



Source: Elaboration based on Gerten et al. 2011

Table 5.2 Summary of findings: blue water availability (cap^{-1} year^{-1})

Blue water availability	Countries
Between 750-1000 m^3	Egypt, Libya, Iraq, Turkey
Between 200-500 m^3	Syria, Algeria, Iran, Tunisia, Morocco, Oman, Lebanon, Saudi Arabia
<200 m^3	Yemen, Kuwait, Israel, Jordan, UAE, Qatar

Source: Elaboration based on Gerten et al. 2011

Table 5.3 Summary of findings: total food-water availability (m^3 cap^{-1} year^{-1}) and percentage increase

Total food-water	Countries	Percentage

availability		increase (%)
>1000 m³	Morocco	255
	Tunisia	185
	Syria	179
	Iran	156
	Algeria	152
	Turkey	143
	Iraq	68
	Libya	48
	Egypt	2
Between 250-650 m³	Yemen	175
	Jordan	172
	Oman	76
	Lebanon	49
	Saudi Arabia	26
<250 m³	UAE	128
	Qatar	82
	Israel	78
	Kuwait	43

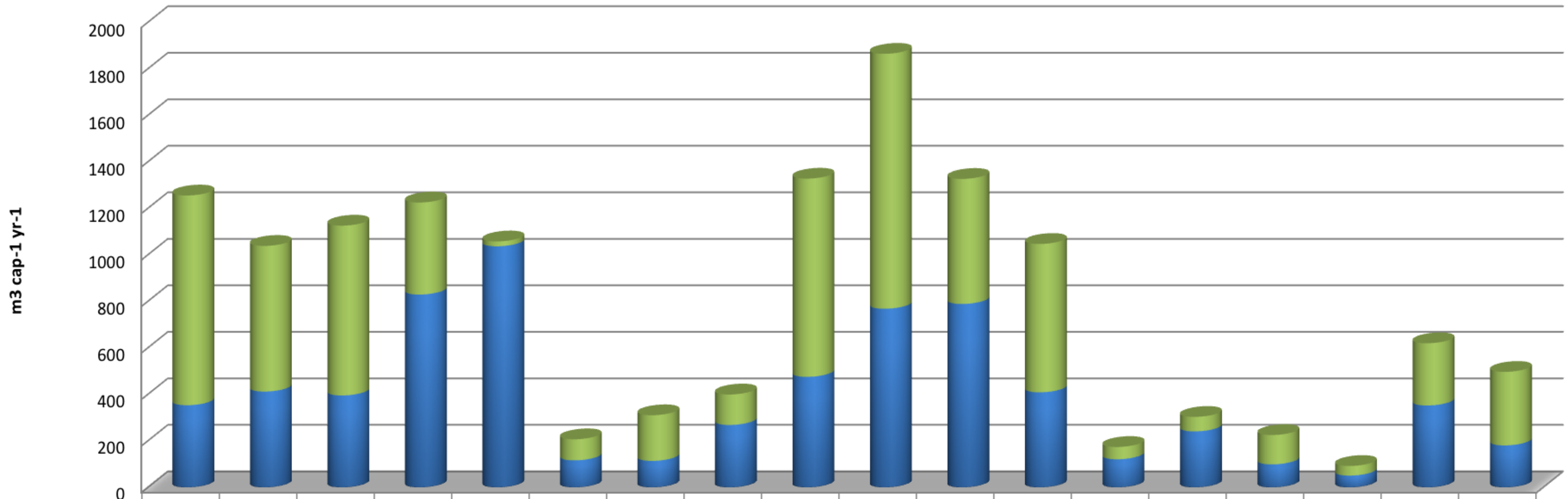
Source: Elaboration based on Gerten et al. 2011

5.4.2 Green and blue water shares

Figure 5.4 shows the MENA countries' total food-water availability by differentiating the two sources available for food production, that is green and blue water resources. Green water accounts for a substantial share of food-water in many of the MENA economies. In half of the region's countries, it exceeds 50% of total food-water availability. These countries are Algeria, Morocco and Tunisia in North Africa; Iran; Turkey, Jordan and Syria in the Middle East; and Yemen and UAE in the Arabian Peninsula. In Israel, Iraq, Oman and Qatar, green water accounts for over 40% of total food-water availability. The most green-water abundant country is Turkey, with an availability of 1,096 m³ per person per year. In Morocco, Algeria, Tunisia, Syria, Iran and Iraq, annual green water availability ranges between 900 and 500 m³ per person. It is between about 400 and 100 m³ per person per year in Libya, Yemen, Oman, Jordan, Lebanon, and

UAE. Finally, green water availability is below 100 m^3 per person per year in Israel, Saudi Arabia, Kuwait, Qatar and Egypt. Table 5.4 summarises the main findings of this section.

Figure 5.4 Green and blue water shares in total water availability (m^3 cap^{-1} year^{-1}, averaged over the period 1971-2000)



	Morocco	Algeria	Tunisia	Libya	Egypt	Israel	Jordan	Lebanon	Syria	Turkey	Iraq	Iran	Kuwait	Saudi Arabia	UAE	Qatar	Oman	Yemen
Green Water	902	626	730	396	21	91	196	131	852	1096	538	638	53	63	126	41	268	316
Blue Water	353	412	395	829	1037	116	114	268	475	768	789	409	121	241	99	51	352	181

Source: Elaboration based on Gerten et al. 2011

Table 5.4 Summary of findings: green water availability (cap^{-1} $year^{-1}$)

Green water availability	Countries
Over 1000 m^3	Turkey
Between 500-900 m^3	Morocco, Algeria, Tunisia, Syria, Iran, Iraq
Between 400-100 m^3	Libya, Yemen, Oman, Jordan, Lebanon, UAE
<100 m^3	Israel, Saudi Arabia, Kuwait, Qatar, Egypt

Source: Elaboration based on Gerten et al. 2011

5.4.3 Water availabilities and requirements for food production

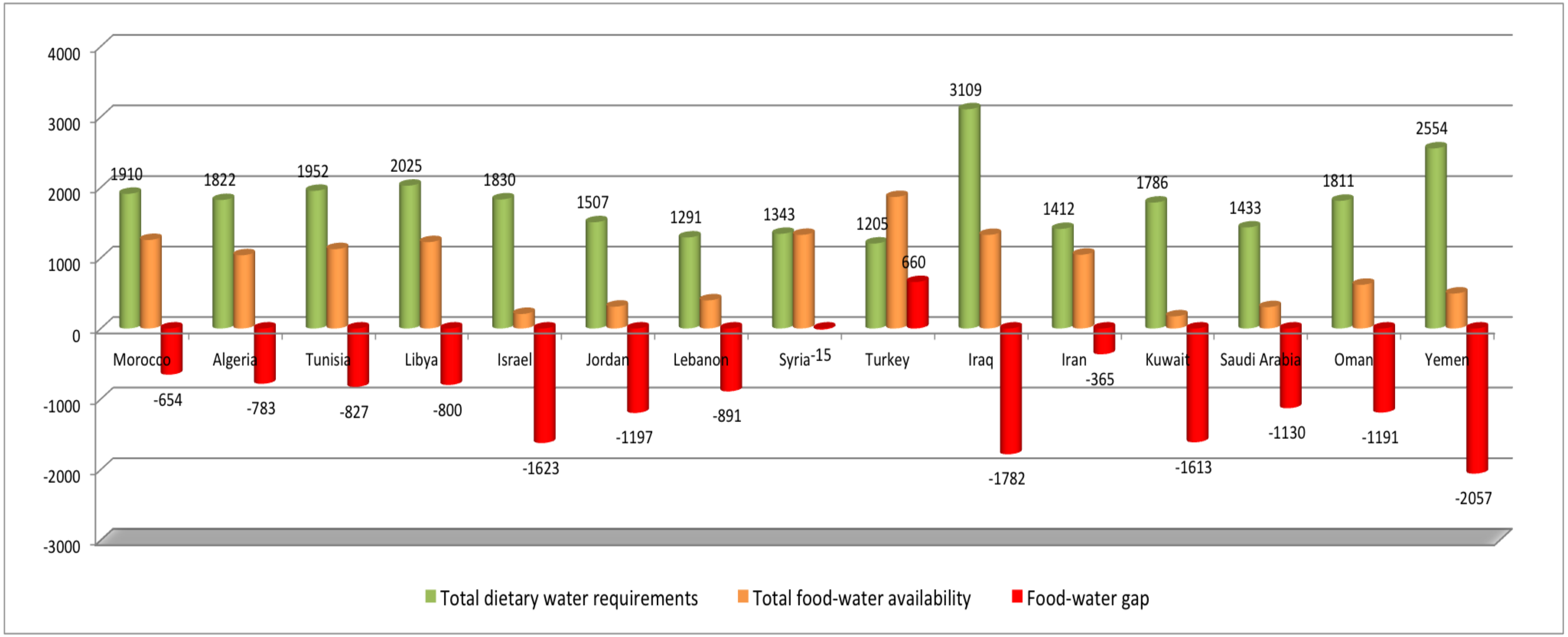
Figure 5.4 illustrates the relationship between total food-water availability and the water requirements for a balanced diet of 3,000 kcal per person per day, and the MENA economies' food water gap[17]. The food-water gap is defined as the difference between total food-water availability and total dietary water requirements. The water requirements for a balanced diet of 3,000 kcal per person per day vary greatly among countries. Different dietary water needs result from countries' different crop water productivities, which are determined in turn by climatic conditions, as well as yield levels and water management. In Iraq, for instance, over 3,000 m^3 per capita per year are needed to produce the diet; whereas in Yemen and Libya, the dietary water requirements range between 2,000 and 2,500 m^3. The rest of the countries in the MENA show annual dietary water requirements exceeding 1,200 m^3 per capita, which is above the global average of 1,095 m^3 per capita identified by Gerten *et al.* (2011).

As illustrated by Figure 5.5, all the MENA economies, with the exception of Turkey, *cannot* meet the water requirements for producing the targeted diet. Total available food-water resources (orange bar) are in fact far below than total dietary

[17] Data on dietary water requirements were not available for Egypt, UAE and Qatar, which are therefore excluded from this analysis.

water requirements based on crop water productivities (green bar). Yemen has the highest food-water gap in the region (over 2,000 m^3 per capita per year). In Kuwait, Israel and Iraq, the food-water gap exceeds 1,500 m^3 per capita per year, whereas it ranges between 1,500 and 1,000 m^3 in Jordan, Oman and Saudi Arabia. Finally, the food-water gaps of Lebanon, Tunisia, Libya, Morocco, Algeria and Iran are below 1,000 m^3 per capita per year. The different degrees of food-water scarcity in the region's economies will be assessed in the next section. Table 6 summarises the main findings of this section.

Figure 5.5 The MENA food-water gap (m^3 cap^{-1} $year^{-1}$, averaged over the period 1971-2000)



Source: Elaboration based on Gerten et al. 2011

Table 5.5 Summary of findings: the food-water gap (cap^{-1} year^{-1})

Food-water gap	Countries
Over 2000 m³	Yemen, Kuwait, Israel, Iraq
Between 1500-1000 m³	Jordan, Oman, Saudi Arabia
Below 1000 m³	Lebanon, Tunisia, Libya, Morocco, Algeria, Iran

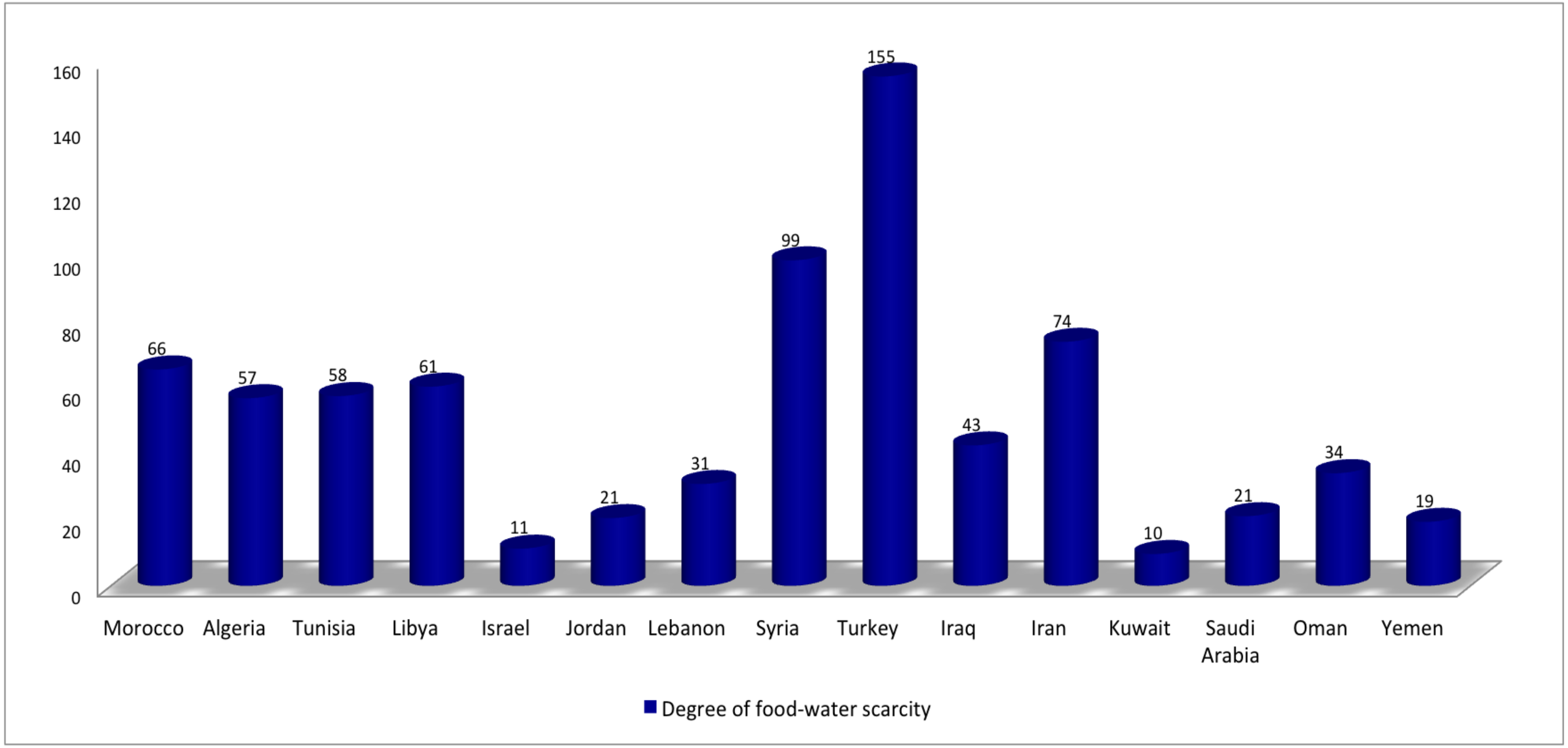
Source: Elaboration based on Gerten et al. 2011

5.4.4 Degrees of food-water scarcity

The degree of food-water scarcity is here defined as the percentage ratio between a country's individual total availability of food-water and their total water requirements for producing a diet of 3,000 kcal per capita per day. Countries with food-water scarcity metrics of over 100% are indicated as *food-water secure*; between 75 and 100% as *relatively food-water secure*; between 50 and 75% *relatively food-water scarce*; between 25 and 50% as *food-water scarce*; below 25% as *severely food-water scarce*. It is noteworthy to say that the data deployed refer to water scarcity considered at the national scale and that, if the analysis were pursued at the subnational (grid) level, the picture would change as some of the countries considered here endure different climatic conditions within their territory.

As illustrated in Figure 5.6, all the MENA countries, with the exception of Turkey, have food-water scarcity degrees that are below the threshold of food-water security (100%). However, there are substantial differences between countries. For classification purposes, Syria is considered as relatively food-water secure, although its food-water scarcity level is 99%, as is Iran (74%). The rest of the MENA countries are classified as follows. Morocco, Libya, Tunisia and Algeria are relatively food-water scarce; whereas, Iraq, Oman and Lebanon are food-water scarce, with values comprised between 25 and 50%. Saudi Arabia, Jordan, Yemen, Israel and Kuwait are classified as severely food-water scarce. In the cases of Yemen and Oman, the very high volumes required for the dietary requirements seem to determine to a great extent the degree of food-water scarcity. Table 5.6 summarises the main results of this section.

Figure 5.6 Degree of food-water scarcity in the MENA countries (%)



Source: Elaboration based on Gerten et al. 2011

Table 5.6 Summary of findings: the degree of food-water scarcity

Degrees	Countries
Food-water secure	Turkey
Relatively food-water secure	Iran, Syria
Relatively food-water scarce	Morocco, Libya, Tunisia, Algeria
Food-water scarce	Iraq, Oman, Lebanon
Severely water scarce	Saudi Arabia, Jordan, Yemen, Israel, Kuwait

Source: Elaboration based on Gerten et al. 2011

5.4.5 First order and second-order resource availability in the MENA countries

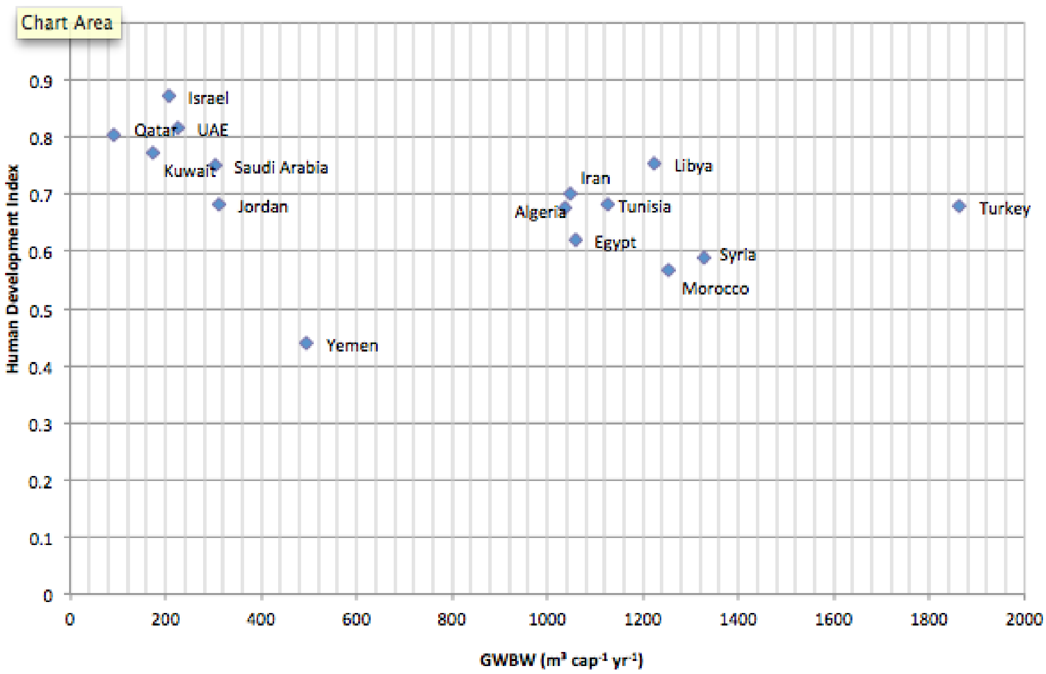
This section relates total food-water availability (hereby defined as the availability of local green and blue water resources for food production) to the socio-economic 'adaptiveness' of the MENA economies. The study by Earle (2011) attempted to analyse the same relationship in a number of political economies in Africa and the Middle East (namely, Israel and Yemen) without considering, however, the availability of the *full* water resources available for food production, which include not only blue but also green water resources.

Figure 5.7 illustrates the relationship between per capita green and blue water availability and the socio-economic development of the MENA countries. Food-water availability is deployed as a measure of first-order resource availability. The HDI is used to account for second-order resource availability. As previously stated, the index provided by UNDP (2013) depicts the overall development of a country by considering educational levels, income and also nutrition levels (more details are provided in the methodology Chapter 4).

As shown in the Figure, socio-economic 'adaptiveness' is not correlated to the availability of food-water resources. Israel shows one of the lowest per capita water availability in the region but it is rich in second-order resources. The GCC economies are also food-water scarce but show high levels of socio-economic development.

Consistently with previous studies (Ohlsson and Turton 1999, Turton 2000a, 2000b), it is argued in this study that the availability of second-order resources determines the capacity to cope with first-order resource deficits by providing options or coping strategies, which are not available to poorly diversified countries. These coping strategies include the development of desalination facilities and also the option of securing populations' food-water needs through virtual water 'imports'. The availability of second-order resources thus determines the resilience and adaptation capacity of a country to local first-order deficits. Countries like Egypt, Syria, Morocco, and, above all, Yemen face more acute water problems as water scarcity is combined with low socio-economic adaptiveness.

Figure 5.7 Food-water resources in relation to socio-economic 'adaptiveness' in the MENA



Source: Elaboration based on Gerten et al. 2011 and UNDP 2013

5.5 Conclusions

The overarching aim of this chapter was to increase understanding of the MENA water and food-related challenges by analysing capacity of the region's countries to secure the food needs of their populations with the water resources available locally. The study hypothesised that most of the region's economies face food-water scarcity as the water available locally is less than the water requirements for securing the production of an adequate daily calorific intake per person, with a balanced share of animal and vegetal products.

In order to corroborate this hypothesis, first, an assessment of the water resources available for food production was carried out. This assessment included not only water in surface bodies and aquifers (blue water), but also the water in the root zone (green water). Green water underpins food security globally, although it is generally ignored by conventional water scarcity assessments. The volumes of soil or green water used for crop and livestock production globally have had no metrics until very recently. This source of water had never been taken into account in the national water resource budgets of the MENA political economies, although it provides water for dryland winter farming and grazing.

The analysis in this chapter has demonstrated that green water is relatively abundant in the northern part of the Near East (such as, Iran, Turkey and Syria) and in some parts of North Africa (Morocco, Tunisia and Algeria); whereas it is negligible in Israel, Kuwait, Saudi Arabia and Qatar. By assessing total (green plus blue) water availability in the MENA region, this study fills a gap in the literature. It also increases knowledge on the *actual* water resources available for food production in the region. It is important to distinguish the two sources of water – green and blue – as they fundamentally differ in terms of alternative uses and opportunity costs.

Secondly, the chapter investigated the extent to which the MENA countries are faced with water scarcity for food production by relating individual water resource availabilities with the water requirements to produce a dietary intake of 3000 kcal per day, with 80% vegetal and 20% products, considered as a benchmark for hunger alleviation. The analysis demonstrated that *all* the MENA countries face food-water scarcity, although to different extents, with the exception of Turkey. Food-water scarcity is more acute the Arabian Peninsula (Oman, Saudi Arabia Kuwait and Yemen), as well as in some countries in the Near East (Lebanon, Israel and Jordan).

The chapter has contributed more in-depth understanding of the MENA region's water issues by analysing the state of local water resources *vis-à-vis* the food requirements of the region's economies. The following chapter will investigate the extent to which the MENA economies have achieved food-water security over the past few decades, and have bridged the gap between water supply and demand, by relying on international food trade.

6. Virtual Water 'Trade' in Agricultural Products in the Middle East and North African region

6.1 Introduction

The overarching aim of this chapter is to investigate the role that international trade has played in underpinning the food-water security of the Middle East and North African political economies over the past few decades. As argued in the previous chapters of this study, water resources and agriculture have a very close relationship as the production of agricultural commodities – *food* in particular – requires far more water than any other economic sector or human activity. The analysis developed in this chapter will deploy the concept of *virtual water* to indicate the water 'embedded' in agricultural commodities, which is invisibly 'exchanged' across boundaries as a result of international trade. This market-mediated water 'transfer' has been referred to as *virtual water 'trade'*[18]. The insight behind the concept is that if one country exports (imports) a water-intensive product to another country, it also 'exports' ('imports') water in virtual form. Given the large magnitude of water used for agricultural production, virtual water can be seen as an additional source of water for resource-deficit countries and as an instrument for improving water use efficiency at the global level.

The present chapter will explore the nexus between water, food and international trade by providing a *comprehensive* assessment of the MENA engagement in

[18] As in the previous chapters of the study, the terms 'trade', 'flows', 'imports' and 'exports' when associated with virtual water will be used throughout with inverted commas, the reason being that it is in fact goods that are being traded, not water (Merrett 2003a).

virtual water 'trade' in agricultural products. More specifically, the chapter aims to understand the extent to which international 'trade' in virtual water has provided the MENA economies with water and food security. For this purpose, the 'flows' of virtual water that have entered and exited the MENA region as 'embedded' water in agricultural commodities over the past three decades will be analysed. The hypothesis that will be corroborated is that the MENA economies have relied to a large extent on the 'import' of virtual water from the global system to bridge the imbalance in the MENA region between water demand and supply. Crops will be shown to be the main 'conduit' of virtual water to the region's economies. It will also be argued that the reliance on virtual water 'trade' has been enabled by trade globalisation and a downward trend in food prices over the period 1986-2010. Over this timespan, the world has experienced a price spike in 2008 and another in 2011. Prices are falling again but not yet to 2000 levels, raising concerns about food security in the most food-dependent region in the world (Wright and Cafiero 2011; Breisinger *et al.* 2010).

Agriculture accounts for 99% of the global consumptive use of (green plus blue) water resources (Hoekstra and Mekonnen 2012). For this reason, the analysis will not include virtual water 'trade' in manufactured products and will focus on agricultural products – *food* in particular. Food products, especially animal-based products, are generally water-intensive although the volumes and type of water required to produce different crops vary widely across regions and countries depending on local evapotranspiration and yields (Mekonnen and Hoekstra 2013). Three macro-categories of food commodities, which include a wide range of crops, animal-based products and luxury food items (such as coffee and spices), will be considered. A number of non-edible agricultural commodities (such as plant fibres, oils, animal hides, tobacco), which account however for a tiny share of the virtual water 'embedded' in the MENA and global trade in agricultural products will also be included.

Five main aims are addressed in this chapter. First, the way virtual water 'trade' in agricultural commodities has evolved over the past three decades has been examined. Secondly, the extent to which the MENA countries 'exchange' virtual water within the region and with the rest of the world has been analysed. Thirdly, the region's 'net import' of virtual water and dependency on external water resources, especially with regards to their food needs has been assessed. Fourthly, the 'flows' of virtual water by category of traded agricultural product have been differentiated. Fifthly, the main virtual water 'import' and 'export' trade partners of the MENA region have been identified. By highlighting the magnitude of water entering and leaving the region in virtual form, the analysis aims to show policy-makers that it is necessary to think *beyond* water basins and reconsider water security within the broader context of national, regional and global political economies.

The analysis carried out in this chapter makes an original contribution. First, over the last decade, the virtual water 'trade' phenomenon and its implications for the world's water-deficit economies have been investigated from different perspectives and for different purposes. 'Flows' of virtual water have been assessed for different groups of countries and employing different methodologies. Some of these studies have analysed the dependency on virtual water 'imports' for some of the MENA economies, especially in the Mediterranean area (Yang and Zehnder 2002). Intra-state virtual water 'trade' has also been studied, although to a lesser extent (Faramarzi *et al.* 2010). None of these studies has analysed virtual water 'trade' in a *comprehensive* fashion for the MENA region as a whole. Secondly, the analysis provided in the chapter will be original in that it will differentiate the virtual water 'embedded' in the different categories of agricultural products, focusing on food commodities. Thirdly, none of previous studies has examined the historical dynamics of virtual water 'trade' in the region. By pursuing these aims, the analysis has advanced knowledge and filled a gap in the literature.

The analysis in this chapter will be fundamental for the development of the next analytical chapter of the study (Chapter 7), in which the different sources of agricultural water will be differentiated. It will be shown that the largest share of the virtual water 'flowing' to the MENA political economies 'embedded' in traded food commodities is green (soil) water, a type of water ignored by policy makers in the region. (Chatterton and Chatterton 1996) It will also be demonstrated that green water is also the main source of water of virtual 'exchanged' between the region's economies 'embedded' in intra-regional trade. The following section outlines the overarching research question as well as the set of sub-questions addressed in this chapter. The related hypotheses to be corroborated will also be presented.

6.1.1 Research questions and hypotheses

The first analytical chapter of the study (Chapter 5) has investigated the extent to which the MENA political economies can meet their water requirements for food production through local water resources and answered the first subsidiary question of the study (that is, *"To what extent can local water resources meet the food-water requirements of the MENA political economies"?*). An assessment of the total volumes of water available for food production in the MENA countries was provided. It was shown that the region is endowed not only with *blue* water resources but also with *green* water resources (especially in Iran, Turkey and Syria in the Near East; and Morocco, Tunisia and Algeria in North Africa). It was also demonstrated that, with the exception of Turkey, *all* the MENA countries face food-water scarcity – although to different extents – as the water available locally is less than the water requirements for securing the production of an adequate daily calorific intake per person of a balanced share of animal and vegetal products. Saudi Arabia, Jordan, Yemen, Israel and Kuwait were shown to be *severely* food-water scarce countries, with degrees of food-water scarcity below 25%[19].

The overarching aim of the present chapter is to address the second subsidiary research question of the study, that is: ***What has been the role of international trade in meeting the water requirements of the MENA economies?*** And, more

[19] The *degree of food-water scarcity* has been defined as the percentage ratio between countries' individual total availability of food-water and their total water requirements for producing a diet of 3000 kcal per capita per day (more details are provided in Chapter 5).

specifically: ***To what extent have the MENA countries relied on virtual water 'trade' to secure their food-water needs?*** Five inter-related sub-questions have been identified.

Sub-question 2.1 *To what extent is freshwater appropriation related to the consumption of agricultural goods in the MENA region? What is the contribution of water resources from outside the region to the region's water footprint?*

Hypothesis. The study hypothesises that the consumption of agricultural goods accounts for the largest share of the water appropriated by the MENA economies. The freshwater indicator that will be deployed in order to corroborate this hypothesis is the *water footprint of national consumption.* It is also hypothesised that a substantial amount of this water originates *outside* the region and is thus accessed through the 'import' of internationally traded goods.

Sub-question 2.2 *How has virtual water 'trade' in agricultural commodities evolved over the past three decades, both globally and in the MENA region?*

Hypothesis. The study hypothesises that virtual water 'trade' has increased considerably over the past three decades, both at the global level and in the MENA, especially as a result of an increased liberalization of trade and a downward trend in the price of agricultural commodities. The study will show that the increase in the consumption of water as 'embedded' in agricultural products, observed in the MENA region over the past decades, has largely been met through virtual water 'imports'.

Sub-question 2.3 *What has been the structure of virtual water 'trade' in the MENA over the past three decades? That is, to what extent do the MENA countries 'exchange' virtual water between themselves and with the rest of the world?*

Hypothesis. The study hypothesises that the volumes of 'exchanged' virtual water 'embedded' in intra-regional agricultural commodity trade (*between* the MENA economies) are far lower than the volumes 'embedded' in extra-regional virtual water 'trade' (with the rest of the world). This hypothesis will be corroborated by providing an assessment of the virtual water 'flowing' *within* the MENA (i.e. intra-regional virtual water 'trade'); *entering* the MENA (i.e. the virtual water 'imported' from non-MENA countries) and *exiting* the MENA (i.e. the virtual water 'exported' to non-MENA countries), during the period 1986-2010.

Sub-question 2.4 *Which have been the main virtual water 'trade' partners of the MENA economies?*

Hypothesis. The study hypothesises that the 'import' of virtual water by the MENA economies is mainly extra-regional (between MENA and non-MENA economies); whereas the 'export' of virtual water has occurred, to a large extent, between the region's economies (intra-regional trade). The origin and destination of the MENA 'imports' and 'exports' of virtual water will be analysed in order to corroborate this hypothesis. Virtual water 'flows' will also be differentiated by category of traded agricultural commodity.

Sub-question 2.5 *To what extent have the MENA countries been 'net importers' of virtual water? To what extent are they dependent on virtual water 'imports' to secure their food needs?*

Hypothesis. It is hypothesised that the MENA countries have been major 'net importers' of virtual water over the past few decades, as the volumes of water 'imported' from the global system via agricultural commodity trade are bigger than the volumes of 'exported' virtual water. This hypothesis will be corroborated through an assessment of the MENA countries' 'net imports' of virtual water, i.e. the 'gross import' minus the 'gross export' of virtual water. The analysis will show that all the MENA countries – with the exception of Tunisia – are 'net importers' of virtual water as their 'gross import' of virtual water have been far larger than their 'gross exports'.

This chapter will corroborate these five hypotheses with the ultimate goal of explaining the role of international 'trade' in virtual water for the MENA region's water and food security.

6.1.2 Structure

The chapter has six main sections. The first section has presented the overall aims of the chapter and has presented the main research questions and hypotheses. The next section provides a re-appraisal of the concept of virtual water 'trade' and illustrates the main contributions of the chapter. The third and fourth sections present the results of the analysis. The chapter concludes by discussing the main findings of the research and draws some conclusions.

6.2 Virtual water 'trade': a re-appraisal of the concept

The concept of virtual water, identified by Allan in the early 1990s, highlighted the volumes of water used in the production of both food and non-food commodities. Accordingly, the term virtual water *'trade'* refers to the water 'embedded' in the products that are 'exchanged' among trade partners and 'move' across boundaries. Virtual water 'trade' has enabled water-deficit countries to cope with increasing needs of water for food production and has enabled them to overcome the limits of local hydrological endowments. When a commodity is exported, its virtual water content is implicitly 'exchanged' as well. Vice versa, when a good is imported, the water used in its country of production is 'imported' in virtual terms. The concept has been used to shed light on the role that global food trade has played in mitigating the very serious water deficits of the MENA countries in a politically silent and economically efficient way over the past decades (Allan 2001). Following this approach, the present study aims to provide a comprehensive analysis of the political economy of virtual water 'trade' in the region. It has been highlighted that, by mitigating local water deficits, virtual water 'trade' has prevented social unrest and conflicts (Allan 2003a; Barnaby 2009). However, it has been also unhelpful in that it has enabled procrastination and has delayed the implementation of politically hazardous reforms in the water sector (Allan 2001). Drawing on these studies, the present research aims to provide metrics on the region's virtual water 'trade'.

New perspectives on international trade in agricultural products can be provided by developing a *trade matrix* of value or quantity of the flows of internationally traded commodities in terms of equivalent virtual water 'flows'. This conversion enables us to appraise the invisible implications of commodity trade in terms of water security in both importing and exporting countries. This is particularly true for the assessments of virtual water 'flows' that distinguish the different sources of water 'embedded' in traded commodities. For instance, a country exhibiting a total (green plus blue) net virtual water 'import' could turn out to be a net 'exporter' of blue water if the amount of blue water 'embodied' in its exports exceeds the 'imported' volumes. This is the case of some Mediterranean economies (Antonelli *et al.* 2012).

As explained in Chapter 3 (theoretical background), the concept of virtual water is consistent with the Heckscher-Ohlin theorem (Reimer 2012), predicting that international trade is largely driven by differences in countries' resources (Krugman and Obstfield 2003)[20]. As argued by Reimer, the comparative advantage associated with relative water endowments is often "latent" so that water is *not* a major determinant of trade. Water resources in fact generally account for a tiny share of production costs in agriculture, and tend to be either under-priced from a societal point of view or not priced at all (Reimer 2012: 2). This is the reason why a number of water-scarce countries in the world are net virtual water 'exporters', whereas some water-abundant countries are net virtual water 'importers' (Roson and Sartori 2010). A more detail discussion on these aspects has been provided in Chapter 3.

[20] The critics about the economic underpinning of the virtual water concept initiated by Wichelns have extensively been addressed in the theoretical Chapter 3 of the study.

It has been shown that virtual water 'trade' is dominated by soil (green) water, which represents, from a global perspective, the largest share of water 'embedded' in traded commodities – over 90% of the total water used for the production of export goods (Fader *et al.* 2011). Green water also accounts for the largest share of the global water footprint of crop production (Mekonnen and Hoekstra 2010b). This is to say that the world's most important food exporting economies produce these commodities mainly under rainfed conditions (Yang *et al.* 2006; Liu *et al.* 2009; Fader *et al.* 2011; Hoekstra and Mekonnen 2011). Gross domestic product has been shown to be a major determinant of the current patterns of global virtual water 'trade' (Suweis *et al.* 2011).

The concept of virtual water has globalised the discussion on water security, environmental sustainability, food security and consumption by linking the challenge of water scarcity to global, regional and local trade flows (Roth and Warner 2007). The existence of virtual water 'trade' increasingly calls for a new governance approach that considers water in its *sub-continental* or even *global* dimension, besides that of the river basin (Hoekstra 2008; Chapagain and Hoekstra 2008; Hoekstra and Chapagain 2008). It has been argued that the *globalisation of water resources* "may be part of the transformation to a promising prospect for feeding the world", especially for water-deficit economies (Nyemeyer and Garrido 2011: 3). The globalisation of freshwater, however, also brings risks, as the indirect effects of water withdrawal are increasingly *externalised* to the virtual water 'exporting' economies. About 19% of global water (accounting for 1762 Gm^3 per year) is used to produce and process products for export. In the virtual water exporting economies, water in agriculture, however, is generally priced far below its real cost and the price of the imported commodity does *not* reflect the cost associated with water use (Mekonnen and Hoekstra 2011a). These countries generally have also high water productivity and inputs, including fertilizers and pesticides[21] (Yang *et al.* 2006). The excessive use of these inputs has become a major environmental hazard (Zehnder *et al.* 2003).

[21] Whether the global water 'savings', which are (arguably) brought about by international virtual water 'trade' result from more efficient water resource use or to the higher levels of inputs used in agriculture in the world's exporting economies is still under debate (Yang *et al.* 2006).

The largest share of global virtual water 'flows' – about 80% – originates from only 4% of the total number of connections established through trade (Konar *et al.* 2011; Suweis *et al.* 2011). It has also been shown that the largest *blue* virtual water 'exporters' in the world – the USA, Pakistan, Australia, Uzbekistan, China and Turkey – are *all* facing conditions of water stress (Mekonnen and Hoekstra 2011a). An expansion in irrigated areas in the world's food exporting economies could occur also as a result of the increasing demand for their virtual water, thus exacerbating the local resource depletion and increasing the opportunity cost of the virtual water 'trade'.

Over the past decade, virtual water 'trade' has been computed both for agricultural and industrial products at the global, regional and national level (Hoekstra and Hung 2002; Chapagain and Hoekstra 2003; Zimmer and Renault 2003; Oki *et al.* 2003; de Fraiture *et al.* 2004; Chapagain *et al.* 2005a; Hoekstra and Hung 2005; Ma *et al.* 2006; Yang *et al.* 2006; Galloway *et al.* 2007; Barrat *et al.* 2008; Chapagain and Hoekstra 2008; Konar *et al.* 2011; Fader *et al.* 2011; Suweis *et al.* 2011; Tamea *et al.* 2013; Lenzen *et al.* 2013). Studies on the temporal evolution of "the virtual water trade network" have shown that the global virtual water 'exchange' has progressively increased over the past decades (Carr *et al.* 2012a, 2012b; Dalin *et al.* 2012; D'Odorico *et al.* 2012; Carr *et al.* 2013) and that a small number of actors control this virtual 'network' (Carr *et al.* 2012a; 2012b; 2013).

Virtual water 'trade' and water footprints in some of the MENA countries have been addressed by a number of studies (Jobson 1999; Wichelns 2001; Yang and Zehnder 2002; Hakimian 2003; Yang *et al*. 2003; Elhadj 2004; Nassar 2007; Yang *et al.* 2007; Chahed *et al.* 2008; El-Fadel and Maroun 2008; Nazer *et al.* 2008; El-Sadek 2010; Faramarzi *et al.* 2010; Zeitoun *et al.* 2010; Chahed *et al.* 2011; Antonelli *et al.* 2012; Choucane *et al.* 2013; Soltani 2013; Mohammadi-Kanigolzar *et al.* 2014). The virtual water perspective has also been used to analyse the economic value of cultivating particular crops in the region – namely citrus and banana production in Jordan (Mourad *et al.* 2010). The MENA countries have been shown to be the most food import dependent in the world, together with Mexico, Europe, Japan and South Korea (Mekonnen and Hoekstra 2011a).

None of these studies, however, has provided a *comprehensive* analysis of the virtual water 'trade' phenomenon in the MENA region as a whole by i) assessing the 'flows' exchanged in all the MENA economies; ii) differentiating intra-regional and extra-regional virtual water 'trade'; iii) assessing the main virtual water 'trade' partners; iv) differentiating the percentage share of the different types of agricultural products (such as, crops, animal products etc.) in total virtual water 'imports' and 'exports'; v) identified the extent to which the region's economies are 'net importers' of virtual water.

By pursuing these *five* aims, this study fills a gap in the literature and avoids the limitations of previous studies, and seeks to provide useful insights for water users and decision-makers in the region. The study shows clearly that it is important to differentiate the different contributions of green and blue water resources to the region's virtual water 'trade'. It provides evidence on the different sources, opportunity costs, trade-offs and environmental implications associated with their use. The differentiation of green and blue virtual water 'flows' will be the focus of the next analytical chapter (Chapter 7). The importance of soil water and rainfed farming in underpinning water and food security will be highlighted.

6.3 The MENA water footprints

The aim of this section is twofold. First, to analyse the appropriation of freshwater resources as 'embedded' in the agricultural goods consumed by the MENA populations. Secondly, to provide an assessment of the region's reliance on *external* water resources. This section addresses the first of subsidiary question of this chapter, that is:

To what extent is freshwater appropriation related to the consumption of agricultural goods in the MENA region? What is the contribution of water resources from outside the region to the region's water footprint?

In order to answer these questions, the water footprint of consumption of the MENA economies[22] will be assessed. The *water footprint of national consumption* is defined as the total amount of freshwater that is used to produce the goods and services consumed by the inhabitants of a nation. The main source of data is the global water footprint assessment developed by Mekonnen and Hoekstra (2011a). The period considered is 1996-2005.

Water footprints will be differentiated in three consumption categories (agricultural, industrial and domestic) and by origin of the water used (local water resources or water resources from other countries). It will be shown that the water 'embedded' in agricultural commodities accounts for the largest share of the water footprint of consumption both in the MENA and globally (Hoekstra and Mekonnen 2012). It will also be shown that a considerable proportion of the region's water footprint relates to water resources used in other nations to produce the agricultural and industrial goods consumed by the MENA populations. This component is referred to as the *external water footprint of national consumption*. The dependency on virtual water 'imports' to secure the region's food needs will be the focus of Section 6.5.5.

6.3.1 The water footprint of consumption of the MENA region

Figure 6.1 shows the MENA region's water footprint of consumption by differentiating freshwater appropriation by the different sectors (agricultural, industrial and domestic), over the period 1996-2005. The different contributions of internal and external water resources to the MENA water footprint of consumption are also identified.

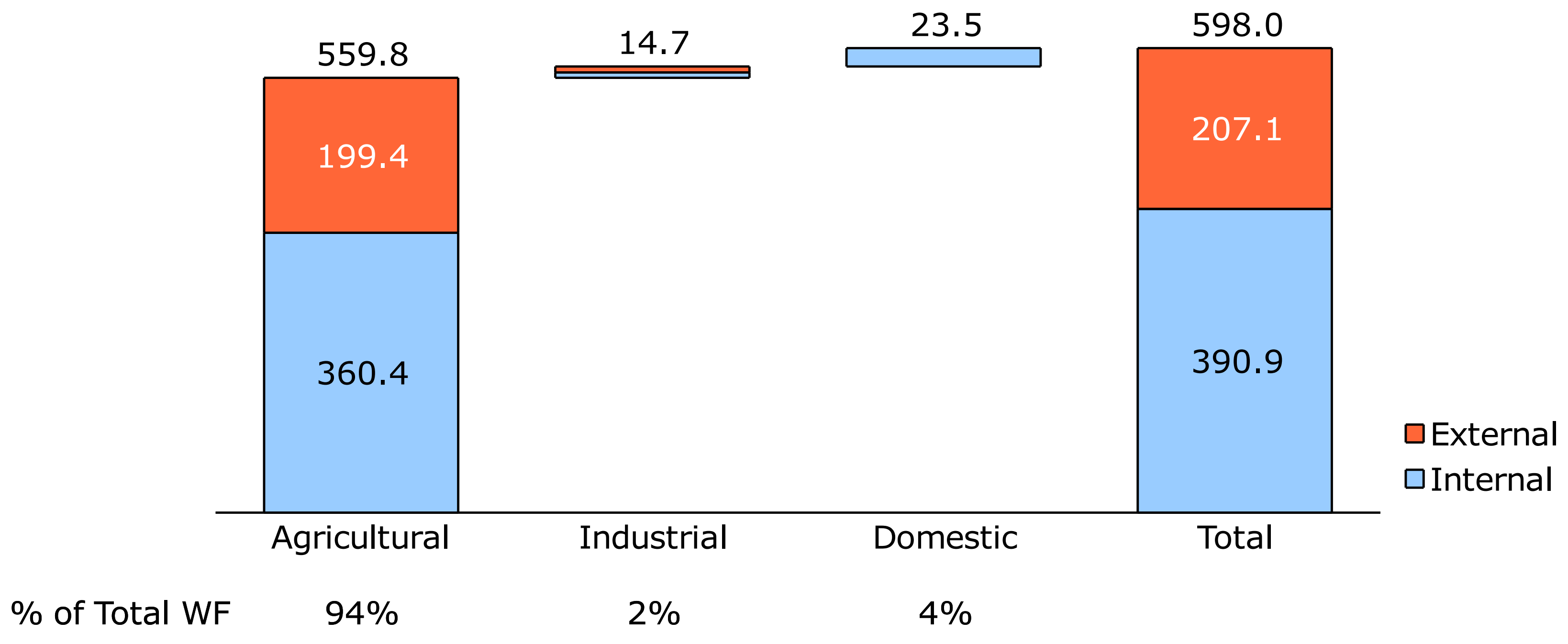
The average water footprint of consumption of the region as a whole is 598 Billion m^3/year and accounts for 7% of the global water footprint of consumption, as estimated by Hoekstra *et al.* (2011a) (Figure 6.2). The consumption of water as 'embedded' in agricultural commodities account for the largest share of the

[22] Bahrain, Qatar, Oman and Iraq are not included in this section due to limitations in the available datasets.

MENA water footprint of consumption (94%); whereas, industrial and domestic water use account, respectively, for 2% and 4% of the total water footprint of consumption (Figure 6.1). This result is in line with global averages (Hoekstra and Mekonnen 2012).

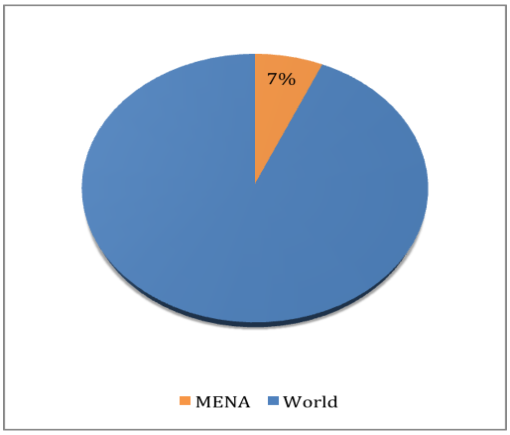
A significant share of the virtual water needed to produce the goods and services consumed by the MENA populations is consumed outside the region and accessed through the import of goods. The *external* component accounts for 35% of the MENA total water footprint of consumption. At the sectoral level, it accounts for 36% of the water 'embedded' in agricultural products (almost 200 Billion m^3/year); and 53% of the water footprint of consumption of industrial products (almost 7 Billion m^3/year). It is worthwhile to say that domestic use cannot have, by definition, an external component, as it can only relate to the use of local water resources.

Figure 6.1 Average water footprint of consumption of the MENA region (Billion m³/year)



Source: Elaboration based on Mekonnen and Hoekstra 2011a

Figure 6.2 The MENA total water footprint of consumption as a percentage of the world's total water footprint of consumption



	Total WF of consumption
World	8,500 Billion m^3/year
MENA region	598 Billion m^3/year

Source: Elaboration based on Mekonnen and Hoekstra 2011a

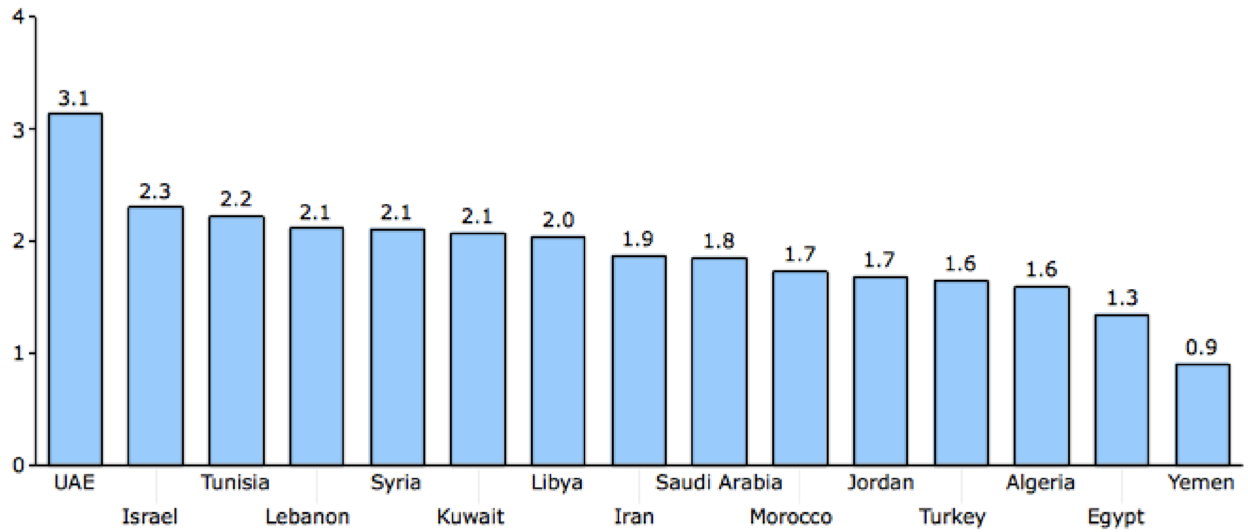
6.3.2 The water footprint of consumption of the MENA economies

The average water footprint of consumption of the MENA is, in per capita terms, 1,905 m^3/year (93% of which is associated with the consumption of agricultural products). This value is 38% higher than the global per capita average, which Hoekstra and Mekonnen (2012) estimated to be 1,385 m^3/cap/year. The largest share (92%) relates to the consumption of agricultural products. Similar consumption patterns are observed in Eastern, Southern and Western Europe; Central Asia; Central Africa; and Latin America. In all these countries, the national water footprint is above the global average (*ibidem*).

The water footprint of consumption of the MENA can partly be explained by the region's dietary habits, as food production is the highest consumptive use of water. As a result of an "industrialisation of the diet" in fact the region has progressively lost its traditional diet in favour of an increased consumption of animal products, pre-processed foods, sugars and fats (Fahed *et al.* 2012), which are generally water-intensive. Since the mid 1960s, the MENA per capita supply of calories has increased from 2,200 kcal/cap/day to over 3,000 in the late 1990s, and is expected to reach almost 3,200 kcal/cap/day in 2030 (WHO/FAO 2003).

Figure 6.3 shows the national water footprints of consumption of the MENA economies, in per capita terms. Countries are ranked in decreasing order. The most diversified economies in the region (very high/high HDI and high/upper-middle income economies) have water footprints in the range of 3,100-2,000 m^3/cap/year. These countries include Israel, some of the region's oil-enriched economies (UAE, Kuwait and Libya), as well as a number of partially industrialised countries (Lebanon, Syria, Tunisia). Saudi Arabia and Iran show water footprints above 1,800 m^3/cap/year; whereas, the water footprints of consumption of the low-middle income (and medium HDI) economies in the region range between 1,700 and 1,300 m^3/cap/year. The only country with a water footprint of consumption below the global average is Yemen (901 m^3/cap/year), which is also the only MENA economy with a *low* Human Development Index (UNDP 2013).

Figure 6.3 The water footprints of consumption of the MENA economies (Thousand m³/cap/year)



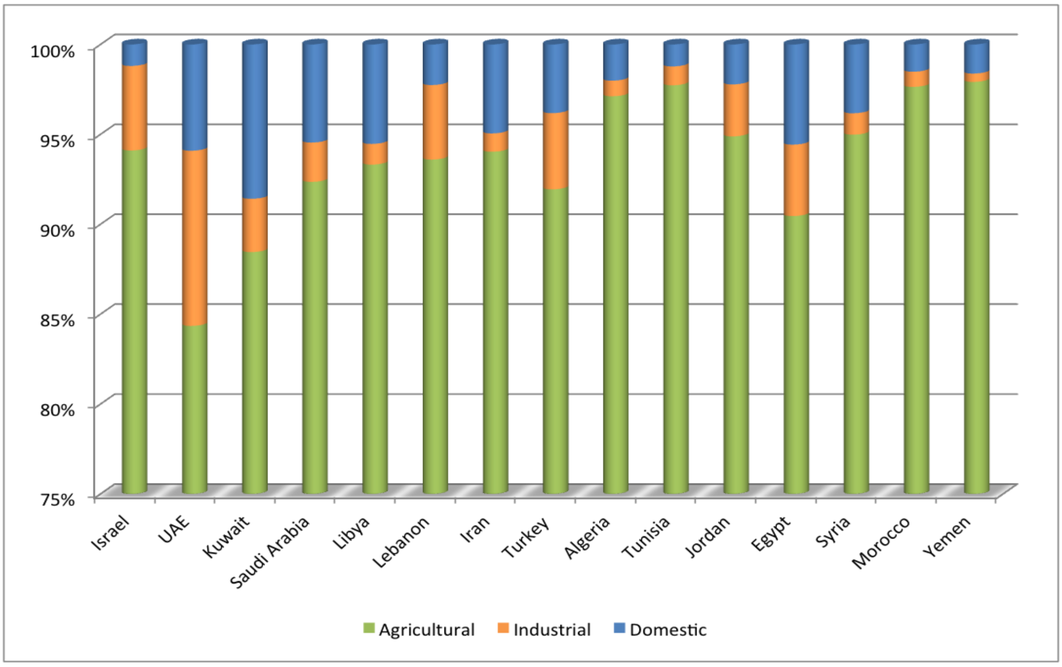
Source: Elaboration based on Mekonnen and Hoekstra 2011a

6.3.3 The water footprint of consumption in the different sectors

As shown in Figure 6.4, the largest share of the water footprint of consumption of the MENA economies, over the period 1996-2005, relates to the consumption of agricultural products. In all the MENA countries, the share of agricultural consumption exceeds 80% of the total water footprint of national consumption (for further details, the reader is referred to the Appendix A).

In the Figure, the MENA countries are ranked according to their HDI level (UNDP 2013), as the study argues that socio-economic diversification is a major determinant of the way water resources are used and allocated. The largest water footprints related to the consumption agricultural products are found in some low-income and middle-income economies in the region (namely, Yemen, Morocco, Tunisia and Algeria). The water footprint associated with the consumption of industrial products is relatively higher in the region's diversified economies (such as UAE and Israel), as well as domestic water use, which is above 5% in some of the oil-enriched economies (Kuwait, UAE, Saudi Arabia, Libya) and Egypt. These results are consistent with global averages as estimated by Mekonnen and Hoekstra (2011a). The water footprints of consumption by sector in the different MENA countries are further illustrated in Appendix B.

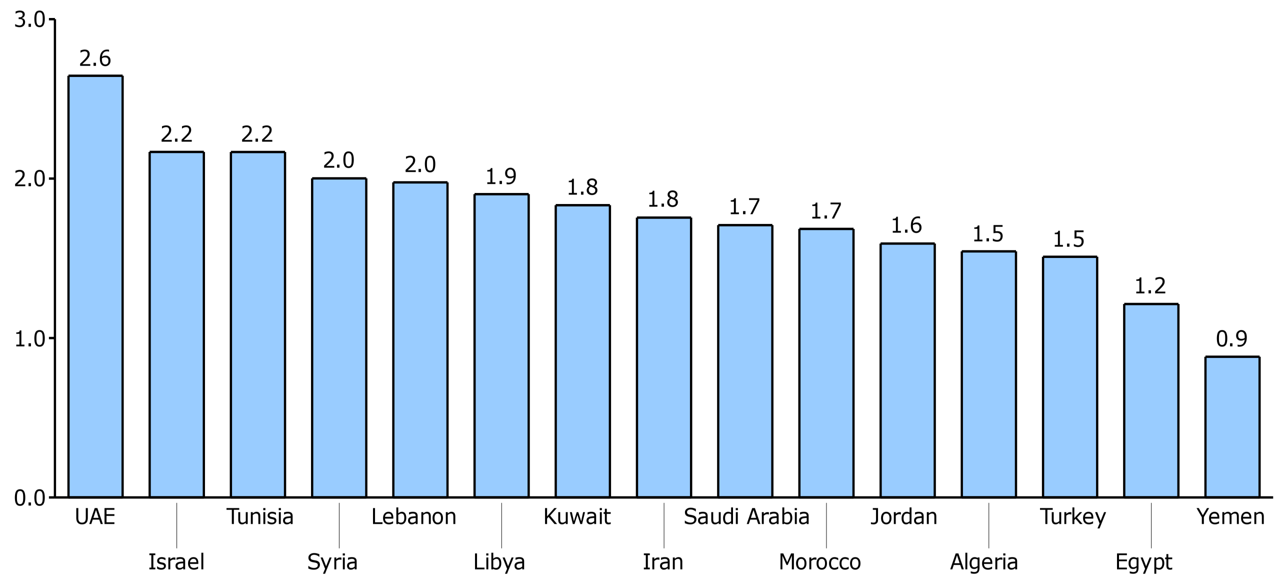
Figure 6.4 Water footprint of national consumption by sector (% per capita) in the MENA countries, ranked according Human Development Index (HDI)



Source: Elaboration based on Mekonnen and Hoekstra 2011a

The average regional water footprint related to the consumption of agricultural products, over the period considered, is 1,772 m^3/cap/year. This amount corresponds to 92% of the average total water footprint of consumption in the region. At the country level, the water footprint of consumption of agricultural goods ranges between about 2,600-880 m^3/cap/year (Figure 6.5). The highest water footprints are observed in UAE, Israel, Tunisia, Syria and Lebanon (2,600-2,000 m^3/cap/year). The next Section (6.4) will analyse the temporal evolution of virtual water 'trade' and the water footprints of production and consumption in the region by focusing exclusively on agricultural products.

Figure 6.5 Water footprint of consumption of agricultural products, by country (Thousand m^3/cap/year)



Source: Elaboration based on Mekonnen and Hoekstra 2011a

6.3.4 Main findings of this section

This section has shown that the water footprint of consumption of the MENA economies is largely determined by the consumption of agricultural products, which accounts for over 90% of the freshwater appropriated by the region. One third of the MENA water footprint of national consumption is *external*, i.e., associated with the 'import' of virtual water from the global system (Section 6.3.1, Figure 6.2).

The analysis has also demonstrated that the average water footprint of consumption of the MENA citizen is 38% higher than the global average (with the exception of Yemen), and also that the most diversified countries in the region show the highest water footprints (in the range of 2,000-3,100 m^3/cap/year). Section 6.4.5.2 will investigate the dependency on *external* water resources for meeting the food requirements of the MENA populations.

This section has answered the first sub-question of this chapter (*To what extent is freshwater appropriation related to the consumption of agricultural goods in the MENA region? What is the contribution of water resources from outside the region to the region's water footprint?*), and corroborated the related hypothesis (see Section 6.1.1. for details). The extent to which the MENA economies have relied, over the past three decades, on international 'trade' in virtual water to secure their needs – especially in relation to food – will be investigated in the following section of this chapter (Section 6.4).

6.4 Virtual water 'trade' in the MENA region

The overarching purpose of this chapter is to understand the role that virtual water 'trade' has played in meeting the water requirements of the MENA economies, in particular in relation to the demand for food, over the past few decades. The focus is on trade in agricultural goods as the consumption of these products accounts for the largest share of the water footprint of consumption of all the MENA political economies. This section will investigate the structure and evolution of virtual water 'trade' in the region in order to answer the overarching question of this chapter (second subsidiary question of the study), i.e.:

What has been the role of international trade in meeting the water requirements of the MENA economies? And, more specifically: ***To what extent have the MENA countries relied on virtual water 'trade' to secure their food-water needs?***

The purpose is to shed light on the extent to which the 'transfer' of virtual water that takes place invisibly as a result of international trade contributes to meeting the requirements of the water-scarce MENA countries. More specifically, the chapter will answer its overarching research question and corroborate the hypotheses presented in Section 6.1.1 by following *four* main steps:

- The virtual water 'embedded' in the production, consumption, import and export of agricultural products, both in the MENA region and globally, will be assessed (*sub-question 2*);
- The volumes of virtual water 'embedded' in the MENA intra-regional and extra-regional trade will be differentiated, as well as the contribution of the different category of agricultural products identified (*sub-question 3*);
- The MENA virtual water 'trade' partners will be identified (*sub-question 4*);
- The chapter will assess the MENA countries' 'net imports' of virtual water in order to understand the extent to which they are dependent on virtual water 'trade' (*sub-question 4*).

The period considered in this analysis is 1986-2010. The overarching hypothesis to be corroborated is that all the MENA political economies rely to a large extent on international trade of agricultural commodities and that this market-mediating mechanism has effectively mitigated the region's water resource deficit over the period considered. As argued in the background chapter (Chapter 2), this solution has been *economically efficient* thanks to the downward trend of food prices until 2003, which has operated at the advantage of the world's water-deficit economies, and *politically convenient*, as it has allowed policy-makers to avoid the implementation of sound reforms in the water sector (Allan 2001). The sources of water 'embedded' virtual water 'flows' entering and exiting the MENA economies will be differentiated in the next analytical chapter (Chapter 7).

6.4.1 Global virtual water 'flows'

The aim Section 6.4.1 and 6.4.2 is to address the second subsidiary question of this chapter, that is:

How has virtual water 'trade' in agricultural commodities evolved over the past three decades, both globally and in the MENA region?

The study hypothesises that virtual water 'trade' has increased considerably over the past few decades, both at the global level and in the MENA, especially as a result of an increased liberalization of trade and a downward trend in the price of agricultural commodities. The study also hypothesises that the increase in the consumption of water as 'embedded' in agricultural products, observed in the MENA over the past decades, has been met mainly through the 'import' of virtual water from the global system.

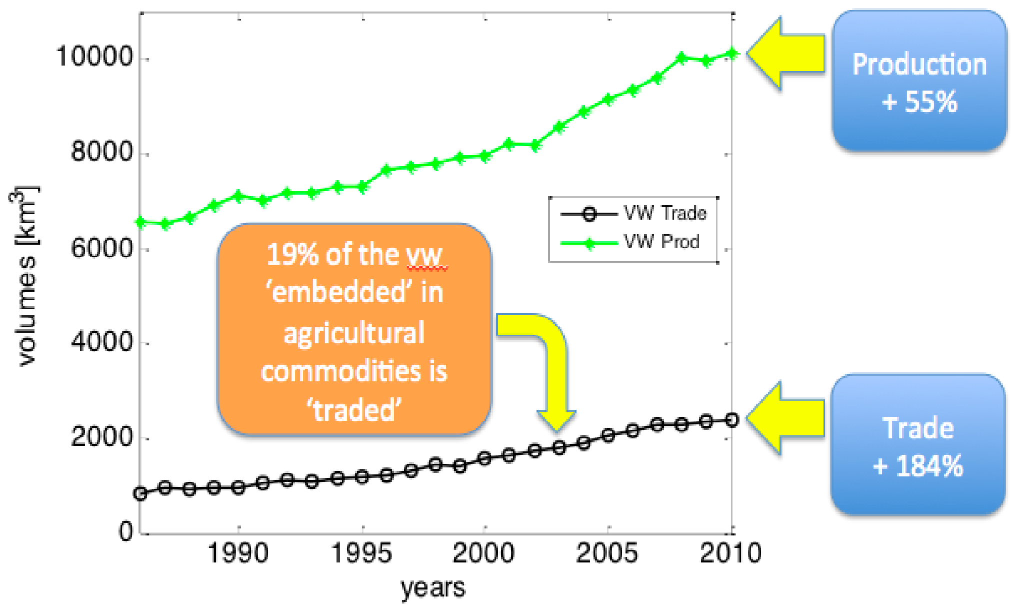
In order to answer the identified research question and corroborate the related hypothesis, the virtual water 'embedded' in the production and trade of agricultural commodities, both at the global level and in the MENA, will be assessed. The theoretical underpinning of this assessment is that, as detailed in the previous chapters (Chapter 2 and 3), international trade in agricultural products and other commodities can be seen as an implicit 'exchange' of the water in virtual form between importing and exporting economies, and also that this mechanism has provided many countries in the world with a remedy to local water deficit. The assessments carried out by Tamea *et al.* (20132) and Carr *et al.* (2013) are the main source of data deployed to assess virtual water 'trade' in the MENA political economies (more details have been provided in the methodology Chapter 4).

Figure 6.6 shows the annual volumes of virtual water 'embedded' in global production (hereby referred to as *water footprint of production*) and trade of agricultural products, over the period 1986-2010. The analysis is based on the assumption that production equals consumption and that the amount of virtual water that is 'traded' is a share of the water 'embedded' in overall production[23]. The agricultural products considered here include crops, animal products, lux-foods and non-edible commodities.

Over the period considered, the volumes of virtual water 'embedded' in the production and trade in agricultural commodities averaged, respectively, 8,046 km^3 and 1,512 km^3. On average, 19% of the water 'embedded' in agricultural products was 'exchanged' internationally. This result is consistent with the global assessment produced by Hoekstra and Mekonnen (2012). Both the global water footprint of production and 'trade' show increasing trends over the period considered. The volumes of virtual water 'embodied' in the production of agricultural goods rose by 55% (from over 6,500 to about 10,150 km^3), whereas 'trade' in virtual water almost tripled (from 840 almost 2,400 km^3) (Table 6.1).

[23] This assumption also implies the absence of storage ad waste for the years considered.

Figure 6.6 Virtual water 'embedded' in global production and trade in agricultural products (1986-2010)



Source: Elaboration based on Tamea et al. 2013 and Carr et al. 2013

Table 6.1 Virtual water 'embedded' in global production and trade in agricultural products: total volumes, average, trend and percentage variation (1986-2010)[24]

	1986 [km³/year]	**1998** [km³/year]	**2010** [km³/year]	**Average** [km³/year]	**Trend**	**Variation**
Production	6.560	7.805	10.146	8.046	Positive	+55%
Trade	840	1.438	2.388	1.512	Positive	+184%

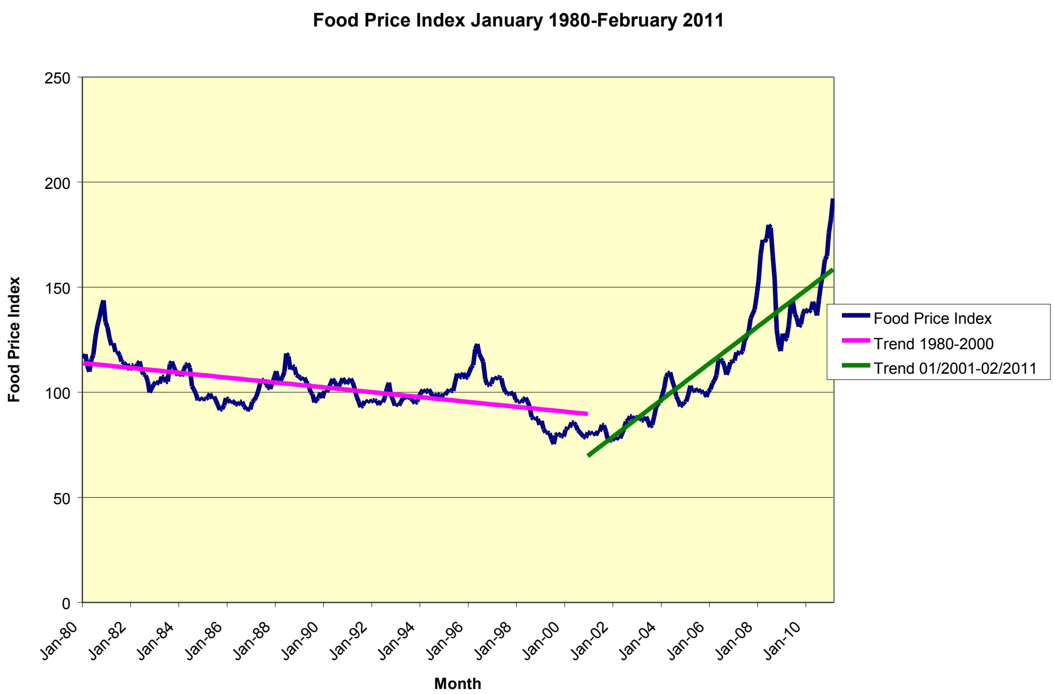
Source: Elaboration based on Tamea et al. 2013 and Carr et al. 2013

The increase in the water footprint of agricultural production can mainly be explained by the increase in the world's cereal production, which grew, over the period considered, at a faster rate than population growth, especially in high-income economies. The overproduction of food as well as the distortions on

[24] Average is calculated over the 25 years. Trend and percentage values refer to the comparison of years 1986 and 2010.

global markets caused by the subsidies to agriculture provided by the EU and the USA, led to overproduction in the subsidised economies and reduced, as a result, world market prices (Marktanner *et al.* 2011). Declines in food prices since 1950 and during almost the whole period considered in this study are a main explanatory factor behind the growth of virtual water 'trade' at the global level (Figure 6.7). It is important to say that, although low food prices have allowed developing countries to keep expenditures on exports low, they have also undermined investments in agriculture modernisation, increased the dependency on food imports and the vulnerability to fluctuations in international commodity markets (Peters 2006).

Figure 6.7 Food prices (1980-2010)

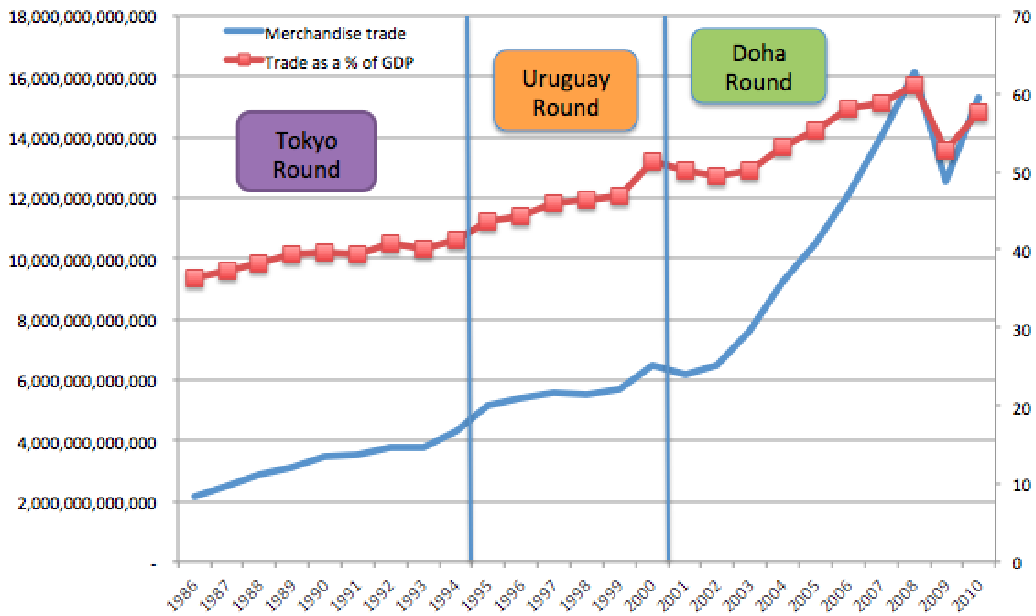


Source: Marktanner et al. (2011: 10)

The increase in global virtual water 'trade' also reflected an *intensification* of international commodity trade as a result of an increased liberalisation of trade and capital markets, as well as technological advancements and decreasing costs of transportation and communication (World Bank 2000: 66). Since 1986, as shown by Figure 6.8, global merchandise trade grew from about 2,138 trillion

US$ in 1986 to over 18,000 trillion US$ in 2010. Over the same period, trade as a percentage of global GDP increased from 36% to almost 60% (World Bank 2014). Over the period considered the growth in global trade was underpinned by a number of international trade negotiations identified in Figure 6.8.

Figure 6.8 Global merchandise trade and negotiation phases (1986-2010)



Source: Elaboration based on Tamea et al. 2013 and Carr et al. 2013

6.4.2 Temporal evolution of virtual water 'trade' in the MENA

The aim of this section is twofold. First, to bring light on the extent to which the MENA economies rely on virtual water 'imports' to secure their needs for food and agricultural products in general, with respect to the rest of the world. Secondly, to investigate the evolution of the MENA virtual water 'trade' over the timespan 1986-2010 by providing an assessment of the annual volumes of virtual water 'embedded' in the import, export, production and consumption of agricultural products for the aggregated MENA economies.

The analysis provided in this section will demonstrate that:

- The MENA region shows, after Europe, the highest volumes of virtual water ‘imports’ per capita in the world;

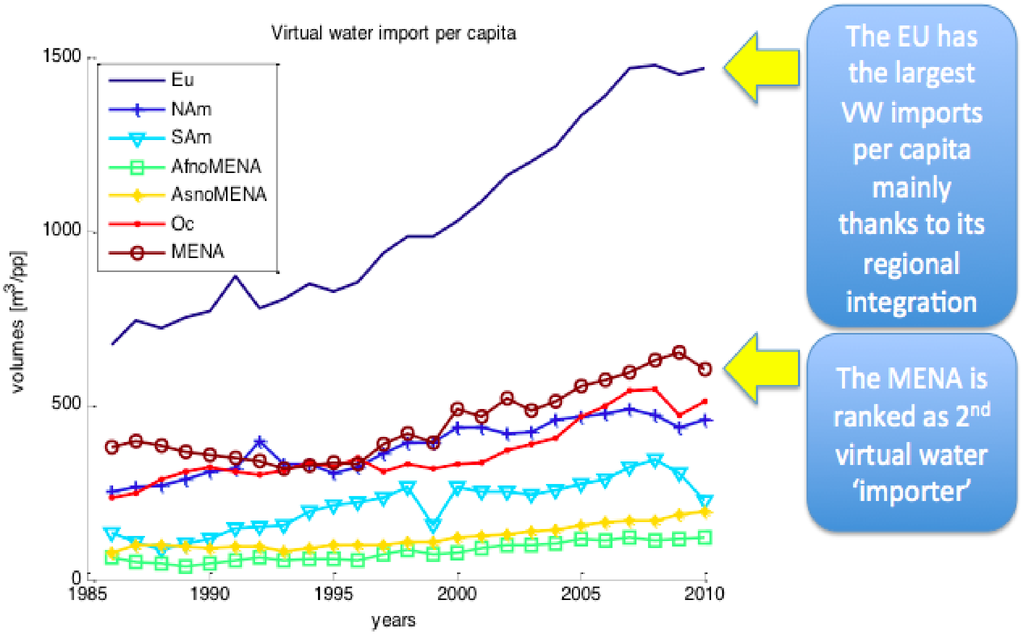
- The increase in the water footprint of consumption of agricultural products, over the period considered, has mainly been met through the ‘import’ of virtual water from the global system;
- The increase in the water footprint of consumption of agricultural products can mainly be explained by the region’s increasing demands for water due to population growth; whereas the increase in virtual water ‘imports’ is more related to the shift towards a more water-intensive diet;
- Food products (crops, animal-based and lux-foods) cover a total share of not less than 95% of all the MENA virtual water ‘imports’, whereas the ‘import’ of virtual water in non-edible agricultural commodities is negligible.

6.4.2.1 Virtual water ‘imports’ in the MENA: a comparison with the rest of the world

Figure 6.9 shows virtual water ‘imports’ per capita associated with trade in agricultural commodities (crops, animal-based, lux-foods and non-edible), in the different regions of the world. The period considered is 1986-2010. The regions analysed are: Europe, Northern America, South America, Africa (excluding the North African countries defined as “MENA”), Asia (excluding the West Asian countries defined as “MENA”), Oceania and the MENA. Regional virtual water ‘imports’ are calculated as the sum of the virtual water ‘imports’ in agricultural products in all the regions’ countries, expressed in per capita terms.

The average MENA citizen is ranked as the second virtual water ‘importer’ in the world, after Europeans. Over the period considered, the ‘import’ of virtual water almost doubled, reaching up to 600 m^3/pc/year. As it will be shown in Section 6.4.3, the virtual water ‘imported’ by the MENA economies as ‘embedded’ in agricultural goods originates mainly from *outside* the region.

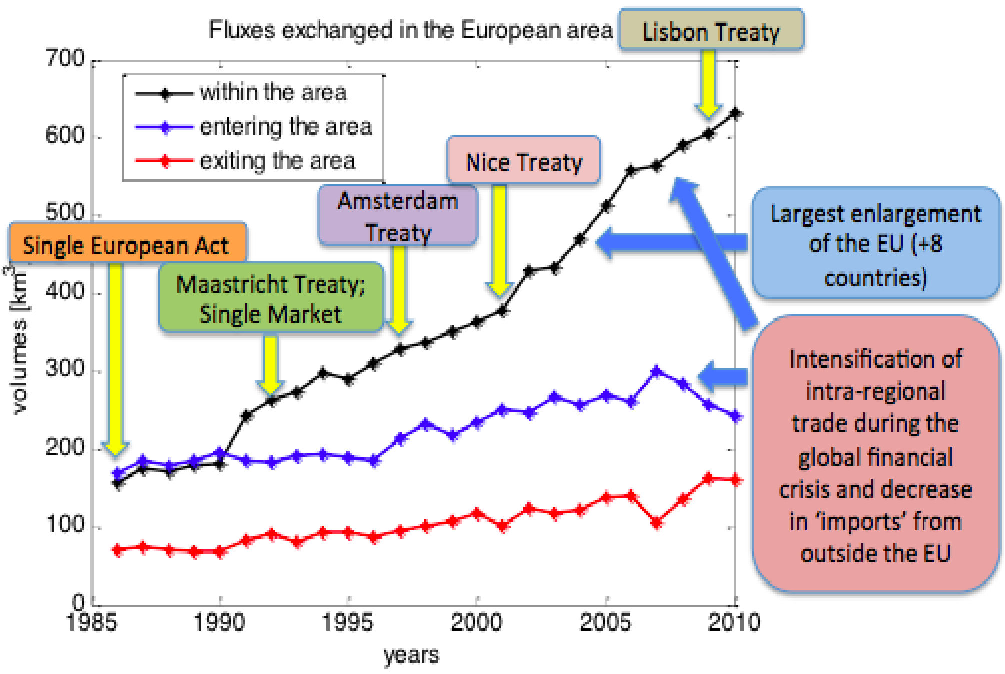
Figure 6.9 Virtual water 'imports' by region (m³/pc/year, 1986-2010)



Source: Elaboration based on Tamea et al. 2013 and Carr et al. 2013

On the contrary, virtual water 'imports' in the EU (the largest virtual water 'importer' in the world) are mainly associated with intra-regional trade, as the EU member states 'exchange' virtual water mainly between themselves (Figure 6.10). The trend is positive over the whole time-span considered. The increase in intra-regional virtual water 'trade' in the EU can be explained not only by the enlargements of the Union from 10 to 27 member states over the period considered, but also by the increasing institutional integration within the area. This integration led to the removal of tariff and non-tariff barriers, the integration of factor markets, monetary integration and cooperation. All these measures triggered a deepening of reciprocal trade between the EU countries; an increase in *trade openness* (measured as the ratio of intra-regional trade to GDP) from 16% to 32% of GDP, albeit with cyclical fluctuations; as well as an increase in real trade value (Mongelli *et al.* 2005). The integration with other (non-EU) partners, on the contrary, has advanced quite slowly over the past decades (Arribas *et al.* 2012).

Figure 6.10 Intra-regional and extra-regional virtual water 'trade' in Europe (km^3/year, 1986-2010)



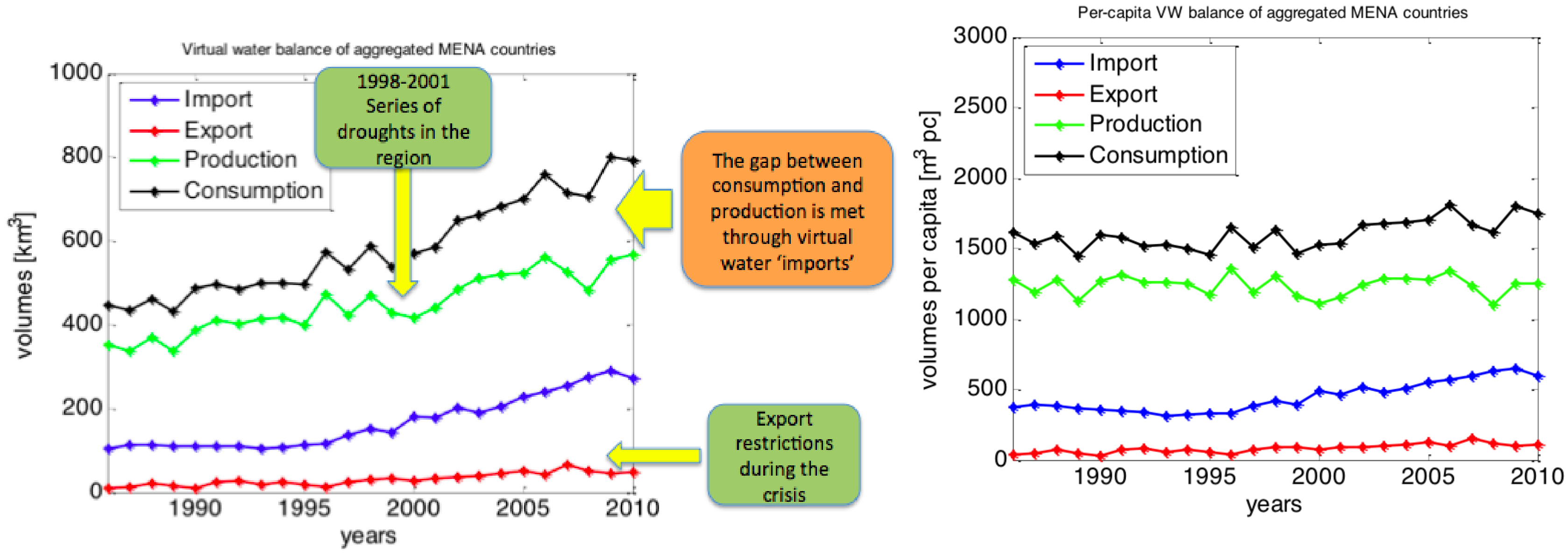
Source: Elaboration based on Tamea et al. 2013 and Carr et al. 2013

6.4.2.2 The MENA virtual water 'balance'

The previous sub-section demonstrated that the MENA has the second highest virtual water 'import' per capita per year in the world. This section aims to provide an assessment of the virtual water 'balances' of the MENA region, that is, the volumes of virtual water 'embedded' in the region's production (hereby referred to as *the water footprint of production*), consumption (hereby referred to as *the water footprint of consumption*), import and export of agricultural products. For details on the methodology, the reader is referred to the methodological Chapter 4 of the study.

The temporal evolution of the MENA virtual water 'balance' (total volumes and volumes per capita), over the years 1986-2010, is shown in Figure 6.11 and summarized in Table 6.2.

Figure 6.11 The MENA virtual water 'balance', total volumes (left) and volumes per capita (right) (1986-2010)



Source: Elaboration based on Tamea et al. 2013 and Carr et al. 2013

Table 6.2 The MENA virtual water 'balance': average, trend and percentage variation (1986-2010)[25]

	Volumes			Volumes per capita		
	Average [km³/year]	**Trend**	**Variation**	**Average** [m³/year]	**Trend**	**Variation**
Import	167	Positive	+162%	446	Positive	+59%
Export	31	Positive	+327%	83	Positive	+160%
WF of Production	449	Positive	+60%	1239	Negative	-3%
WF of Consumption	584	Positive	+77%	1602	Positive	+8%

Source: Elaboration based on Tamea et al. 2013 and Carr et al. 2013

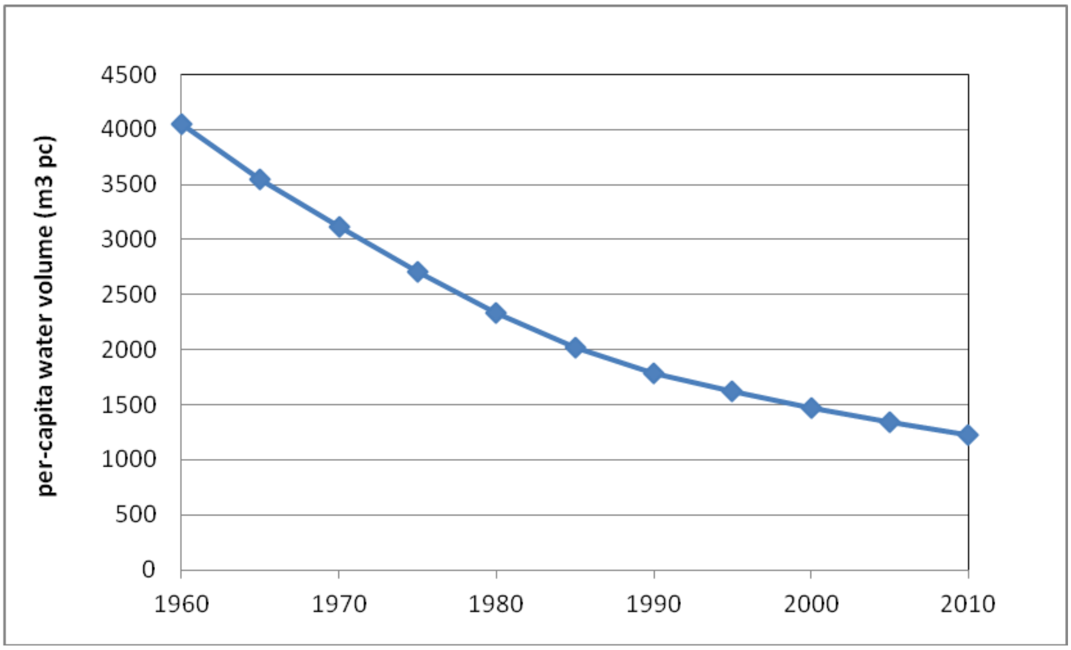
All the volumes of virtual water considered show an increasing trend over the 25-year time span. The highest increase can be observed in virtual water 'exports', which almost quadrupled. Compared with 'imports', the volumes of virtual water 'exports' are negligible (<50 km^3). A steady decrease in virtual water 'exports' is observed after the year 2007, in correspondence of the implementation of government interventions and various economic policies, such as export restrictions and tax reductions on food grains, as a response to the global food price crisis (Breisinger *et al.* 2010). As it will be shown in the Section 6.4.3, while the MENA virtual water 'exports' are equally shared between intra-regional and extra-regional trade in agricultural commodities, the origin of virtual water 'imports' is mainly extra-regional.

The MENA virtual water 'imports' more than doubled – from 104 km^3 in 1986 to 273 km^3 in 2010. Total 'imports' increased substantially in time with greater contributions from Turkey and the United Arab Emirates, which sum up to Iraq, Saudi Arabia and Syria in the last decade (2000-2010). The increase was quite continuous, with some small fluctuations between 1999 and 2003. Food products accounted by far for the largest share of total virtual water 'imports' over the

[25] Average is calculated over the 25 years. Trend and percentage values refer to the comparison of years 1986 and 2010.

whole period considered (more details are provided in Section 6.4.2.3). The increase in virtual water 'imports' over the period considered was accompanied by a dramatic decrease in the region's per capita renewable water resources, which dropped by half, from about 2,000 m^3/yr in 1986 to 1,200 m^3/yr (they were 4,000 m^3/yr in 1960) (Figure 6.12). These metrics, however, do not consider green water and are shown here only as estimates on the MENA total (green plus blue) water availability over time are, to our best knowledge, not available. As argued in Chapter 5, if green water were added, water availability in a number of MENA economies would double.

Figure 6.12 Per capita renewable water resources in the MENA region (1960-2010)

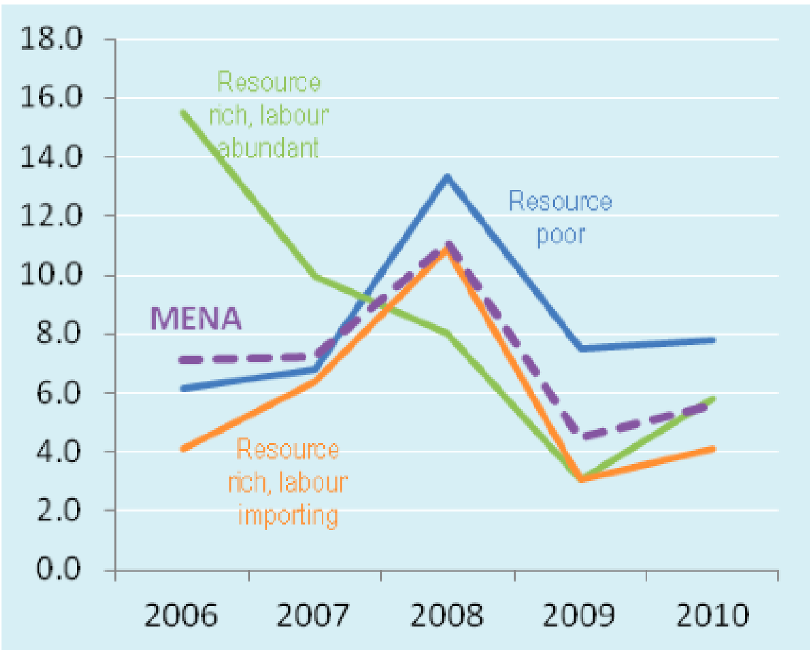


Source: Elaboration based on FAO AQUASTAT 2014

The 'import' of virtual water was facilitated by a downward trend in food commodity prices, which fell, between 1980 and 2001 by 35%. The 2007-2008 spikes seem not to affect virtual water 'imports', which keep on increasing steadily until 2009, although the price for food was 50% higher than in 1980 and 100% higher than in 2000 (Marktanner *et al.* 2011). In these years, the price for oil and fats increased by 106%, cereals 83%, dairy products 56%, sugar 26% and meat 22%. These shocks increased the MENA spending on food imports and also spurred domestic food inflation, especially in Qatar, Jordan, UAE, Oman, Egypt, Lebanon, Kuwait and Libya (Al Masah Capital Limited 2012). Even when international food inflation tuned negative, domestic food inflation in the MENA remained positive.

Consumer price inflation remained relatively higher in the MENA resource-poor countries (which depend on imports to secure their need for food and fuel and also lack the financial resources of to implement compensatory measures to contrast price volatility) than resource-rich countries, affecting the low and middle-income segments of society (O'Sullivan *et al.* 2011) (Figure 6.13). High and volatile international food prices, which spurred in turn an increase in domestic food prices, have been argued to be among the triggers of the Arab Spring protests (Breisinger *et al.* 2011; Woertz 2011; Zurayk 2011).

Figure 6.13 Consumer price inflation in the MENA economies

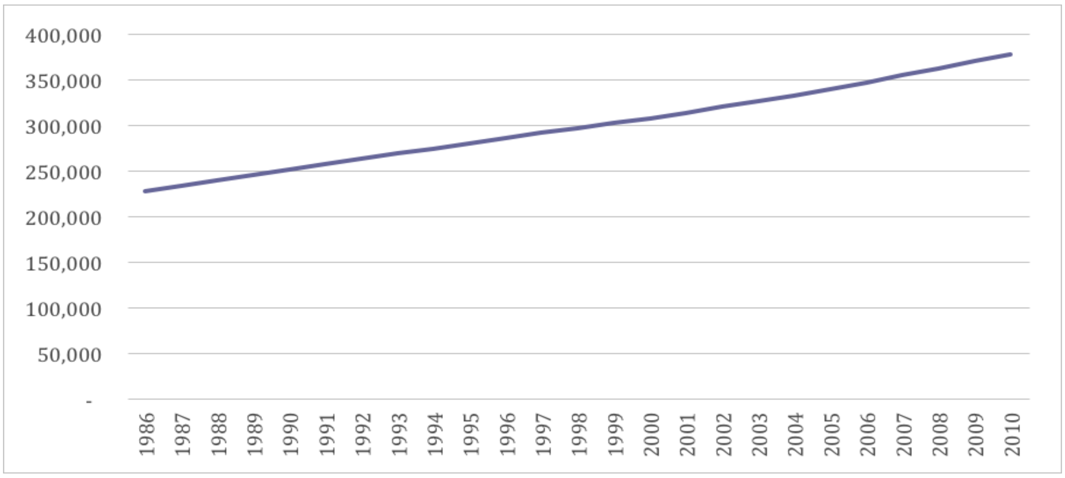


Source: O'Sullivan et al. (2011: 9)

Figure 6.11 also shows that, over the same decades (1986-2010), the water footprints related to the production and consumption of agricultural goods also increased substantially. Production rose by over 60%, albeit with several fluctuations, which can be related to the region's climatic variability. The occurrence of severe and periodic droughts has been shown to be a cause of agricultural production volatility in the region (De Pauw 2005; Shetty 2006). A reduction in the water footprint of production, for instance, can be observed during the period 1998-2001, when a series of droughts affected Iran, Iraq, Jordan, Morocco and Syria, as well as, to some degree, Algeria and Tunisia (FAO 2008). Three of these countries (Morocco, Algeria and Tunisia) are the major food producing countries in the region (Al Masah Capital Limited 2012). Over these years, cereal production dropped to a considerable extent and resulted in an increased import of grains from abroad (De Pauw 2005). In the year 2000, Iran was the world's large importer, with an import of about 7 million tons of wheat (FAO 2008). Over the same period, the water footprint of consumption of agricultural products increased by almost 80%.

Over the period considered, all the trends are markedly positive (as highlighted in the left panel of Figure 6.11), but given the large increase of population in the area, more useful insights can be provided by analysing the right panel of Figure 6.11, showing the MENA virtual water 'balance' in per capita terms. The per capita water footprint of production and consumption remained quite stable over the period, indicating that the increase in total volumes (left panel) can be explained by the extraordinary population growth from about 227 in 1986 to almost 380 Millions in 2010 (Figure 6.14). On the contrary, per capita virtual water 'imports' (as well as 'exports', although to a lesser extent) show a marked positive trend (+60%), which seems to demonstrate that the increase is explained by other drivers, such as the increase in living standards and the shift towards more water-intensive diets.

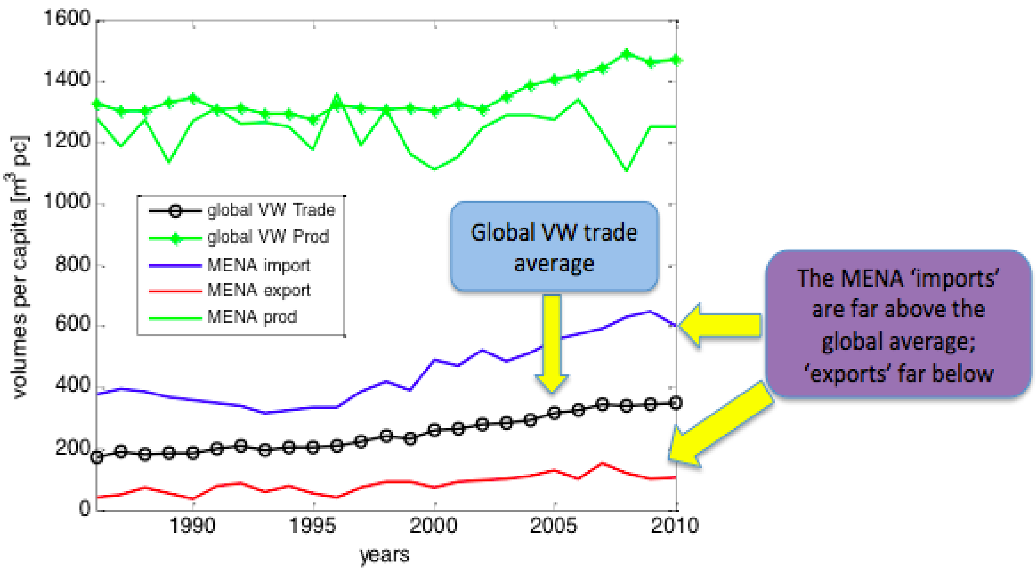
Figure 6.14 Population growth in the MENA (1986-2010)



Source: Elaboration based on UNDESA 2013

It should be noted that the MENA has per capita virtual water 'imports' and 'exports' which are, respectively, far above and below the average volumes of virtual water 'exchanged' globally (Figure 6.15). The water footprints of agricultural production in the MENA region have values that are comparable with global averages, although with much more fluctuation. The volatility of agricultural production in the region, which determines in turn its water footprint of production, can be related to the occurrence and severity of droughts in the area.

Figure 6.15 Comparison between global and MENA per capita virtual water 'flows' and water footprints of production of agricultural products (1986-2010)



Source: Elaboration based on Tamea et al. 2013 and Carr et al. 2013

6.4.2.3 The importance of food products in the MENA virtual water 'imports'

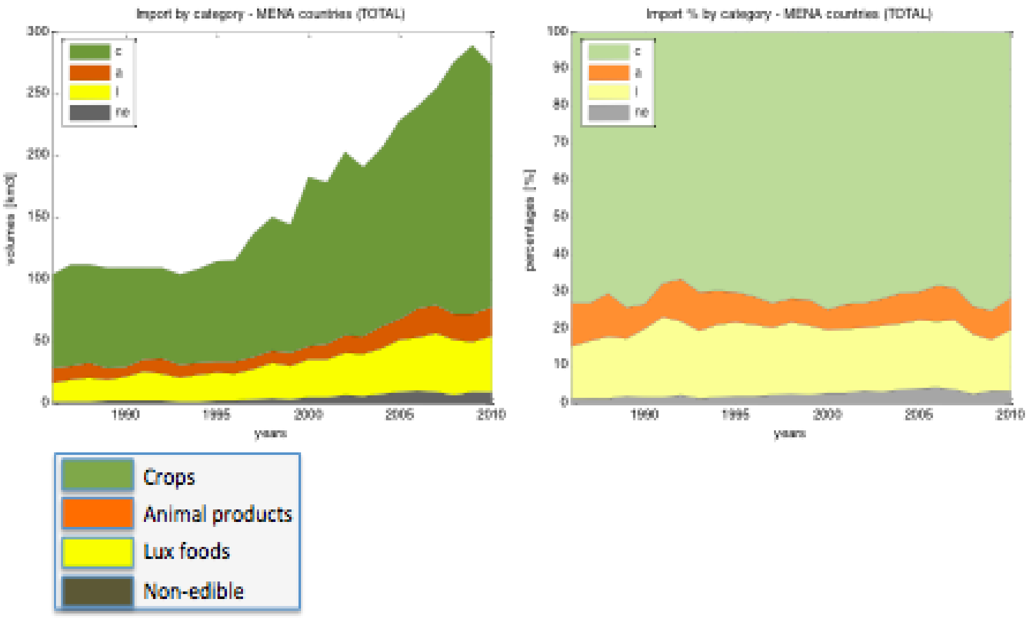
Figure 6.16 investigates the categories of agricultural products composing the virtual water 'import' of the MENA countries (both from MENA and non-MENA countries), differentiating *crops* (c, colour *green*), *animal products* (a, colour *red*), *lux-foods* (l, colour *yellow*) and *non-edible* agricultural commodities (ne, colour *grey*). The full list of agricultural commodities considered in this chapter is provided in the Appendix A. The total volumes of 'imported' virtual water by category of traded commodities are shown in the left panel; whereas the relative contribution (percentage share) of each category of agricultural products to total virtual water 'trade' are shown in the right panel.

The MENA ‘imports’ of virtual water is mainly associated with the import of food products, which account for at least 95% of the total ‘imports’ over the whole time-span considered. On average, crops (including cereals, fruits and vegetables) account for over 70% of total ‘imports’, followed by lux-foods (18%), animal products (8%) and non-edible products (2%). The virtual water ‘flows’ associated with the four different types of agricultural commodities show a substantial increase over the period considered. The highest increase can be observed in non-edible products (+646%), followed by lux-foods (+203%), crops (+156%), and animal products (+97%). The relative contributions of each category (right panel) do not changed much, fluctuating around intermediate values, apart from a steady increase in non-edibles, lasted until recent years. Almost the totality of virtual water ‘imports’ originated from non-MENA countries (more details in Section 6.4.3)[26].

Figure 6.16 The MENA total virtual water ‘imports’ by category of agricultural product: total volumes (left) and percentage shares (right) (1986-2010)[27]

[26] The virtual water ‘embedded’ in *extra-regional* virtual water ‘trade’ only averaged in fact 111.3 km^3 for crops, 26.3 km^3 for lux-foods, 11.8 km^3 for animal products, and 4.2 km^3 for non-edible commodities.

[27] The following legend applies to all the Figures analysed in this chapter: c= crops; a= animal products; l= lux-foods; ne= non-edible commodities.



Source: Elaboration based on Tamea et al. 2013 and Carr et al. 2013

6.4.3 The structure of virtual water ‘trade’ in the MENA region: intra-regional and extra-regional virtual water ‘flows’

The aim of this section is to answer the third sub-question of this chapter, i.e.:

What has been the structure of virtual water ‘trade’ in the MENA over the past three decades? That is, to what extent do the MENA countries 'exchange' virtual water between themselves and with the rest of the world?

In order to answer this question, the MENA intra-regional and extra-regional virtual water ‘trade’ in agricultural commodities will be assessed. The virtual water ‘embedded’ in the different types of traded commodities (including both food commodities and non-food commodities) will also be differentiated.

Intra-regional virtual water ‘trade’ is defined as the ‘exchange’ of virtual water *within* the MENA region that takes place as a result of regional commodity trade. It is important to say that intra-regional virtual water ‘flows’ include *all* the ‘exchanges’ of virtual water between the MENA economies. The traditional differentiation between ‘imports’ and ‘exports’, therefore, does not apply to this type of trade. Extra-regional virtual water ‘trade’ can be defined instead as the ‘exchange’ of virtual water between MENA and non-MENA countries. Extra-regional virtual water 'flows' can be sub-divided into virtual water *entering* the MENA (i.e. virtual water 'imports' from non-MENA countries), and virtual water *exiting* the MENA (i.e. virtual water 'exports' to non-MENA countries). The different types of virtual water 'trade' analysed in this section and the data labels deployed in Figure 6.17 are summarised in Table 6.3.

Table 6.3 Description of categories for intra-regional and extra-regional virtual water 'trade' deployed in this chapter

	Description	Data label
Intra-regional	Virtual water 'trade' between MENA countries	Within the MENA
Extra-regional	Virtual water 'imports' from non-MENA countries	Entering the MENA
	Virtual water 'exports' to non-MENA countries	Exiting the MENA

Source: Author

This section will show that:

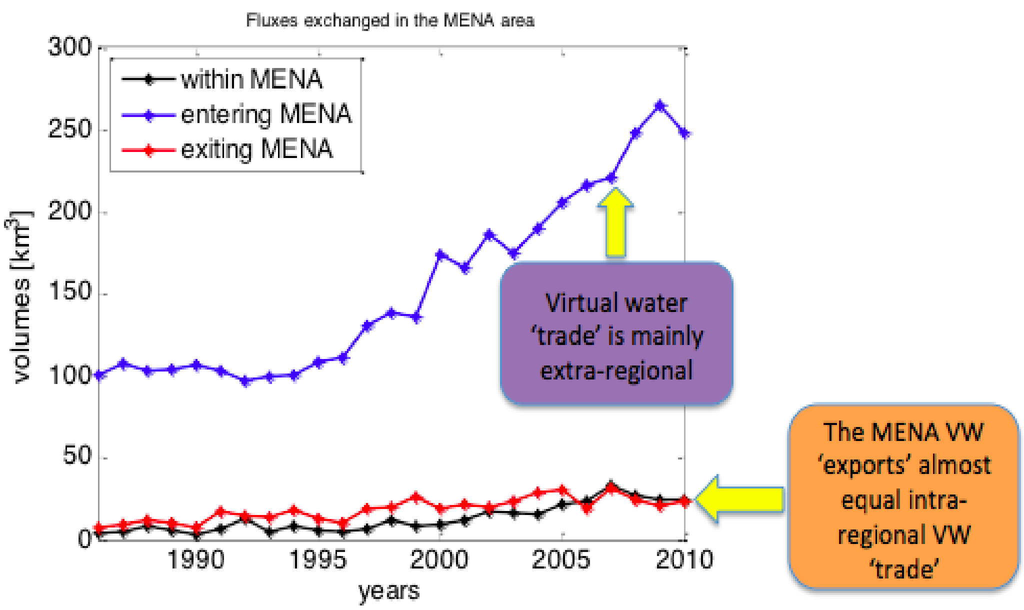
- Almost the totality of virtual water 'imports' originates from *outside* the MENA region;
- They trade between themselves almost as much as they export to non-MENA economies;
- Both total and intra-regional virtual water 'trade' are mainly associated with trade in crops (65-70%), followed by lux foods, animal-based, and non-edible

agricultural products;

- Food products account not only for the largest share of virtual water 'imports' (as shown in Section 6.4.2.3) but also for most of the MENA 'exports'. Non-edible agricultural commodities are negligible in 'imports' but they are relatively more important in 'exports', especially until the year 2005.

The 'flows' of virtual water 'embedded' in the MENA intra-regional and extra-regional trade of agricultural commodities, over the period 1986-2010, are shown in Figure 6.17 and summarised in Table 6.4.

Figure 6.17 Intra-regional and extra-regional virtual water 'trade', total volumes (1986-2010)



Source: Elaboration based on Tamea et al. 2013 and Carr et al. 2013

Table 6.4 Intra-regional and extra-regional MENA virtual water 'trade': average, trend and percentage variation (1986-2010)[28]

	Volumes			Volumes per capita		
	Average [km³/yr]	**Trend**	**Variation**	**Average** [m³/cap/yr]	**Trend**	**Variation**
Within MENA	13	Positive	+534%	33	Positive	+285%
Entering MENA	154	Positive	+148%	413	Positive	+51%
Exiting MENA	19	Positive	+220%	50	Positive	+94%

Source: Elaboration based on Tamea et al. 2013 and Carr et al. 2013

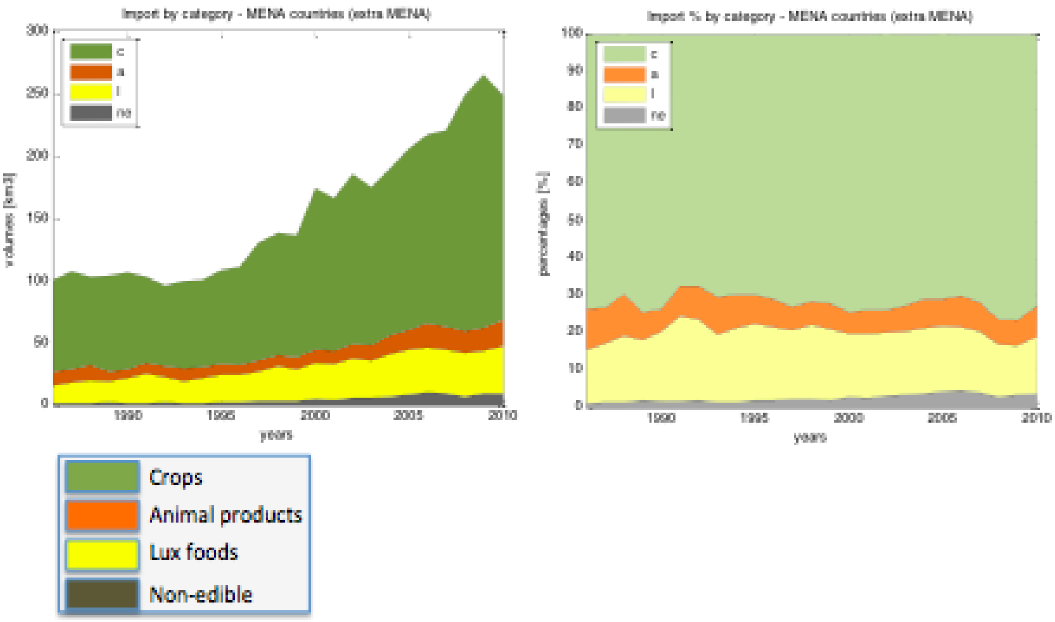
Over the period considered, virtual water 'imports' from non-MENA countries (referred to as *"entering the MENA"* in Figure 6.17) increased from 100 km^3 in 1986 to 248 km^3 in 2010. 'Imports' started rising especially after 1999, although with some fluctuations. As already shown in Section 6.4.2.2, the 2007-2008 food price spikes did not affect the volumes of 'imported' virtual water, despite consumer price inflation and export restrictions by the key food suppliers, such as Argentina, Russia, India and Vietnam (Woertz 2011). As it will be shown in Section 6.4.4, in 2010, almost 60% of the MENA total virtual water 'imports' originated from Brazil (mainly associated with the import of animal products and lux foods, but also crops); the USA (mainly crops, but also non-edible agricultural commodities); Russia, Argentina and Ukraine (mainly crops); and India (crops as well as non-edible agricultural commodities, although to a much lower degree).

The volumes of virtual water 'embedded' in the different types of agricultural products imported (left panel) by the MENA from outside the region and their relative contributions to total virtual water 'trade' (right panel) are shown in Figure 6.18. These volumes almost equal the region's total virtual water 'imports' (from both MENA and non-MENA countries) (Figure 6.16, Section 6.4.2.3). Food imports cover at least 95% of 'imports' from non-MENA countries over the whole

[28] Average is calculated over the 25 years. Trend and percentage values refer to the comparison of years 1986 and 2010.

time-span considered. Crops account for about 70% of total ‘imports’. This fact does not come as a surprise as the MENA region is widely acknowledged as being the largest net importing region of cereals in the world, whose import cover more than half of its internal consumption (Wright and Cafiero 2010; Sadler and Magnan 2011). The region imports 27% of all the wheat traded globally (Ahmed *et al.* 2013).

Figure 6.18 Virtual water ‘flows’ *entering* the MENA by category of agricultural product: total volumes (left) and percentage shares (right) (1986-2010)

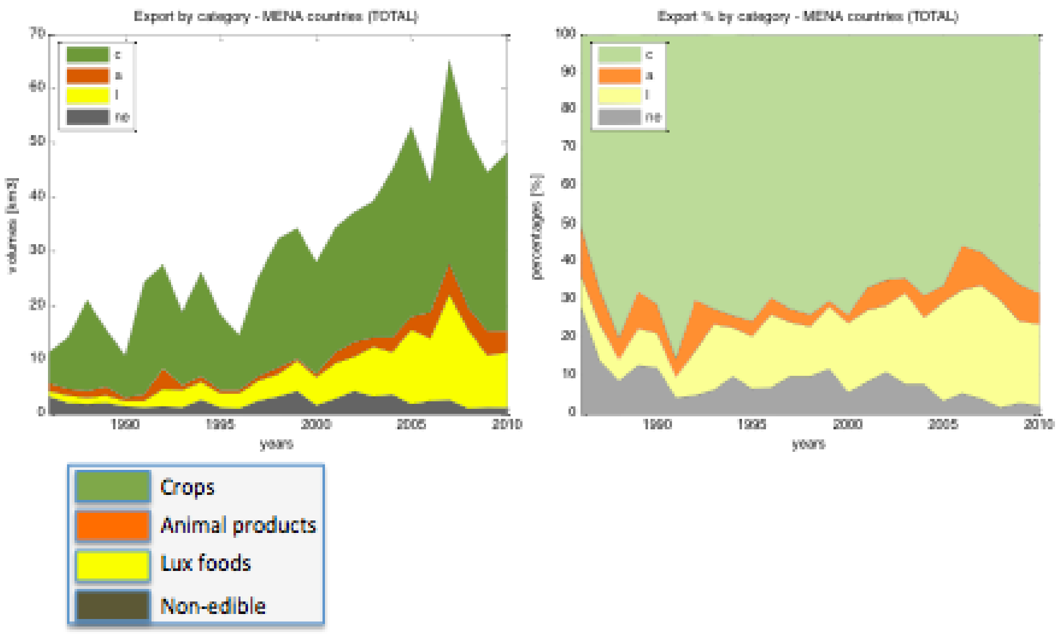


Source: Elaboration based on Tamea et al. 2013 and Carr et al. 2013

As regards the MENA virtual water ‘exports’ to non-MENA countries (referred to as *“exiting the MENA”* in Figure 6.17), they more than tripled during the period considered (from 7 km^3 in 1986 to 24 km^3 in 2010), although the volumes are far lower than virtual water ‘imports’. The stagnation of the MENA exports in non-oil commodities, as well as the very low ratio (7%) of non-oil exports relative to GDP (Iqbal and Nabli 2010; Richter 2012), explain such low volumes of ‘exported’ virtual water. As it will be shown in Section 6.4.4, in 2010, the main extra-MENA virtual water ‘export’ trade destinations outside the MENA region were three EU countries, namely Italy, Germany and France (mainly associated with the export of crops, but also non-edible commodities); as well as the USA, Russia, Indonesia and Hong Kong (mainly crops).

As shown in Figure 6.19, the virtual water ‘embedded’ in crops accounted on average for almost 70% of the MENA total virtual water ‘exports’, followed by lux-foods, animal products and non-edible products. The virtual water ‘exports’ implicit in the MENA export in agricultural commodities increase substantially over time (especially crops and lux-foods), with the exception of non-edible commodities (-67%). The contribution of crops over the period considered is by far the largest (values range between 50 and 70% of total ‘exports’), followed by lux-foods, whose contribution rose from less than 10% in 1986 to over 20% in 2010. The share of animal products remains stable (around 10%); whereas non-edible commodities drop from about 25% in 1986 to less than 3% of total ‘exports’ in 2010.

Figure 6.19 The MENA total virtual water ‘exports’ by category of agricultural product: annual volumes (1986-2010)



Source: Elaboration based on Tamea et al. 2013 and Carr et al. 2013

As regards intra-regional virtual water ‘trade’ (referred to as “*within the MENA*”), as shown in Figure 6.17, the MENA economies ‘exchange’ virtual water between them almost as much as they ‘export’ it to the rest of the world. Over the period 1980-2010, mutual ‘trade’ in virtual water almost sextupled, reaching up to 24 km^3 in 2010[29]. The increase in intra-regional virtual water ‘flows’ reflects the increasing degree of integration between the MENA economies over the past two decades (Ekanayake and Ledgerwood 2009). From 2000 to 2009, for instance, intra-MENA merchandise exports grew from about 16,000 Million US$ to over 70,400 US$ (Böhme 2010). Mutual trade of the MENA economies, however, is half below its potential and very low if compared with other regions in the world, such as the EU (Behar and Freund 2011). Intra-MENA trade accounts in fact for only 5.9% of the region’s total merchandise exports and 5.1% of total imports. Intra-MENA exports are higher than 10% of total exports only in Egypt, Jordan, Lebanon and Syria; and about 10% of total imports in Libya. The existence of tariff and non-tariff barriers, as well as the exclusion of the MENA countries from trading blocks and agreements, hinder the region’s integration and is seen as an

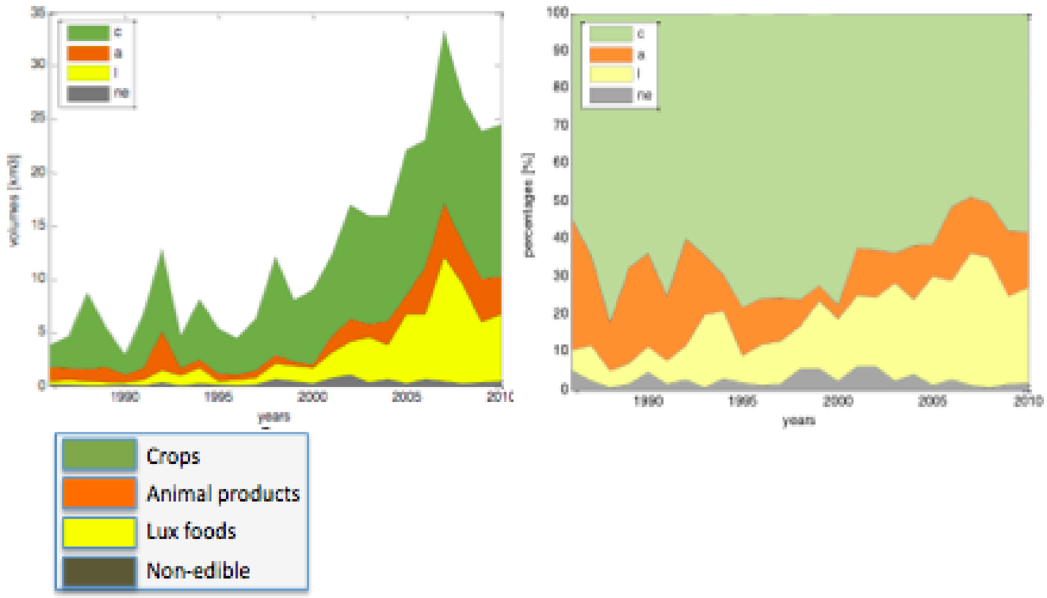
[29] As previously stated, these ‘flows’ include *all* the ‘exchanges’ of virtual water between the MENA economies.

obstacle to the region’s economic development and foreign direct investment (Richter 2012).

The ‘exchange’ of virtual water between the MENA economies is mainly associated with trade in crops, which account, on average, for 65% of total intra-regional virtual water ‘flows’, followed by lux-foods (17%); animal products (15%); and non-edible commodities (3%) (Figure 6.20 left panel). All the volumes of virtual water increased substantially over the period considered, although with several fluctuations. The relative contribution of each category to intra-regional virtual water ‘trade’ changes, over the period considered, quite consistently in the case of animal products (decreasing from 34% to 15% in 2010), and also for lux-foods (from 6% to almost 30% in 2010) (Figure 6.20 right panel). As it will be shown in Section 6.4.4, intra-MENA virtual water ‘trade’ is mainly associated with the export of crops and lux-foods from Turkey (as well as animal products, although to a much lower extent); and animal products from Syria, Jordan and Iran. In 2010, the destinations of intra-regional virtual water ‘exports’ are mainly: Iraq (mainly crops and, to a lesser extent, animal products and lux-foods); the UAE (mainly crops); Saudi Arabia, Syria, Jordan, Morocco (mainly crops but also animal products); Algeria (mainly lux-foods); and Egypt (crops).

Figure 6.20 Virtual water ‘trade’ *within* the MENA by category of agricultural product: annual volumes (left) and percentage shares (right)

(1986-2010)



Source: Elaboration based on Tamea et al. 2013 and Carr et al. 2013

6.4.4 Virtual water 'trade' partners

The aim of this section is to address the fourth sub-question of this chapter, that is:

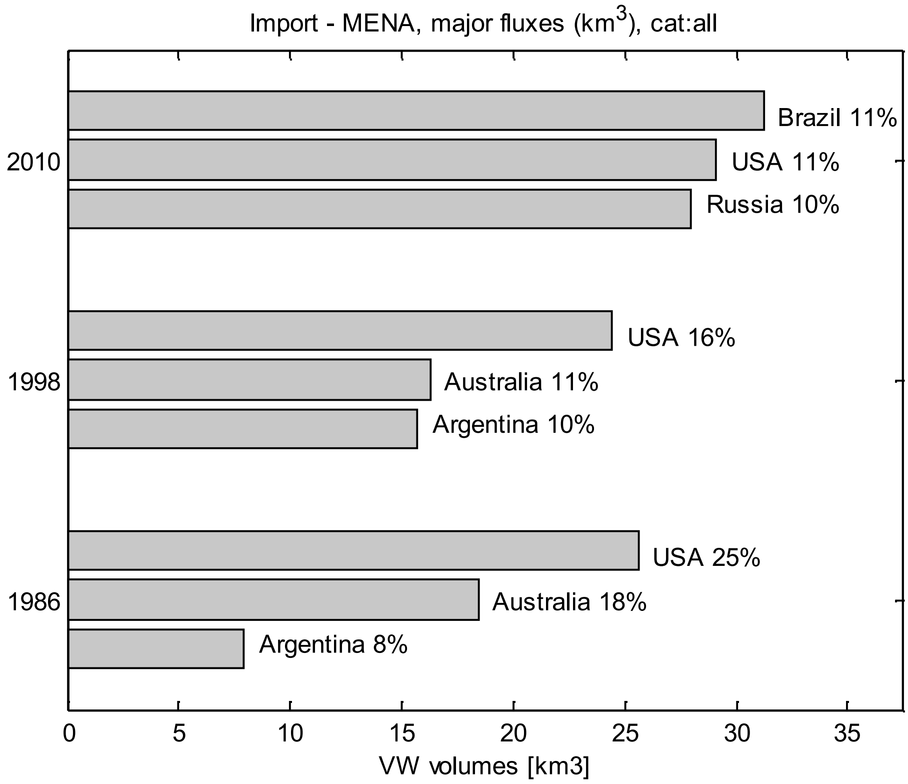
Which have been the main virtual water 'trade' partners of the MENA economies?

In order to answer this question, the volumes of virtual water 'exchanged' between the MENA region and its trade partners will be assessed for the period 1986-2010. Virtual water 'imports' and 'exports' will also be differentiated by category of agricultural commodity.

6.4.4.1 'Import' partners

Figure 6.21 illustrates the three major virtual water 'import' trade partners of the MENA region in the years 1986, 1998 and 2010, and their relative contributions to the region's total virtual water 'imports'. Countries are ranked by volume of virtual water 'imported' via agricultural commodity trade.

Figure 6.21 The MENA virtual water 'import' trade partners: volumes and percentage share of total 'imports' (1986-2010)



Source: Elaboration based on Tamea et al. 2013 and Carr et al. 2013

In 1986, the USA accounted for 25% of the MENA total virtual water 'imports', followed by Australia (18%), and Argentina (8%). The three countries were still the major virtual water 'import' trade partners in 1998, although with quite significant changes in their relative contribution to total 'imports', increased by 45% over these years, as shown in Section 6.4.2.2. In 2010, two BRICs economies, namely Brazil (11% of total 'imports') and Russia (10%), are ranked as two of the main 'import' partners of the MENA region, together with the USA (11%). This fact reflects the increasing importance of trade between the BRICs economies with the MENA countries over the past decade. Between 2001 and 2010, trade with BRICs grew from about 6% to almost 14% of total trade in the MENA. The BRICs are not only key suppliers of agricultural products but also providers of manufactured goods and foreign investments in a number of MENA economies (Masetti *et al.* 2013).

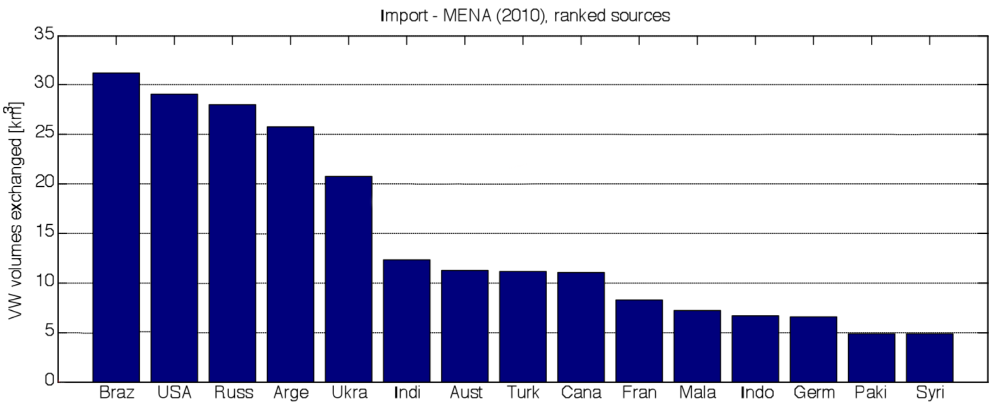
Virtual water 'flows' from Brazil, the USA, Russia, Argentina and Ukraine (between 20 and 30 km^3/yr each) account for over 50% of the MENA total 'imports' in 2010 (Figure 6.22). Interestingly, two MENA countries – namely, Turkey (about 10 km^3/yr) and Syria (less than 5 km^3/yr) – are ranked among the top virtual water 'import' trade partners of the MENA.

Russia, one of the largest producers of wheat in the world, is a key supplier of wheat (especially for Egypt, the largest wheat importer in the world since the mid 2005[30]) and barley in the region (Al Masah Capital Limited 2012; FAOSTAT 2014); whereas virtual water 'imports' from Brazil are mainly associated with animal products. The USA 'exports' virtual water mainly as 'embedded' in crops but also non-edible products. Brazil, the USA and the Russian Federation are three of the major exporting economies in the world, accounting respectively for 5.2%, 10.4%, and 1.9% of global trade in agricultural commodities in 2012 (WTO 2013). Argentina and Ukraine 'trade' virtual water as embedded in crop exports, as well as India (also non-edible, although to a much lower extent), Australia, Turkey (also lux-foods and animal products) and Canada.

Some of the MENA virtual water 'import' trade partners (such as the USA, Australia, Pakistan, India, as well as Turkey and Syria) endure, to different extents, water stress conditions (Smakhtin *et al.* 2004). 'Exporting' virtual water from these countries may thus entail risks for their natural resource base. An overview of the water resource situation of the MENA virtual water 'import' trade partners is provided in Table 6.5. Further analysis on green and blue water resources in these countries will be provided in Chapter 7.

Figure 6.22 The MENA virtual water 'import' trade partners: volumes (2010)

[30] An exception is the year 2008, when the first importer of wheat in the world was Japan, followed by Algeria and Egypt (FAOSTAT 2014).



[1] 'Brazil'
[2] 'USA'
[3] 'Russia'
[4] 'Argentina'
[5] 'Ukraine'
[6] 'India'
[7] 'Australia'
[8] 'Turkey'
[9] 'Canada'
[10] 'France'
[11] 'Malaysia'
[12] 'Indonesia'
[13] 'Germany'
[14] 'Pakistan'
[15] 'Syria'

Source: Elaboration based on Tamea et al. 2013 and Carr et al. 2013

Table 6.5 Water resources in the MENA virtual water 'trade' partners

	Total renewable water resources per capita[31] [m^3/cap/yr]	**Agricultural water withdrawal**[32] [%]	**Blue water scarcity of local river basins**[33]
Brazil	44.649	58	Low
Russia	31.220	20	Low
Argentina	21.147	66	Low
Ukraine	2.961	6	Low
France	3.474	13	Low
Malaysia	22.550	25	Low
Indonesia	8.952	91	Low
Germany	1.867	1.5	Low
Turkey	3.128	74	From low to moderate
Canada	90.385	N. A.	From low to moderate

[31] Averaged over the period 1998-2007. Own calculation based on FAO AQUASTAT database. Website accessed on 05 January 2014.

[32] Averaged over the period 1998-2007. Own calculation based on FAO AQUASTAT database. Website accessed on 05 January 2014.

[33] Period 1996-2005, based on Hoekstra and Mekonnen 2011.

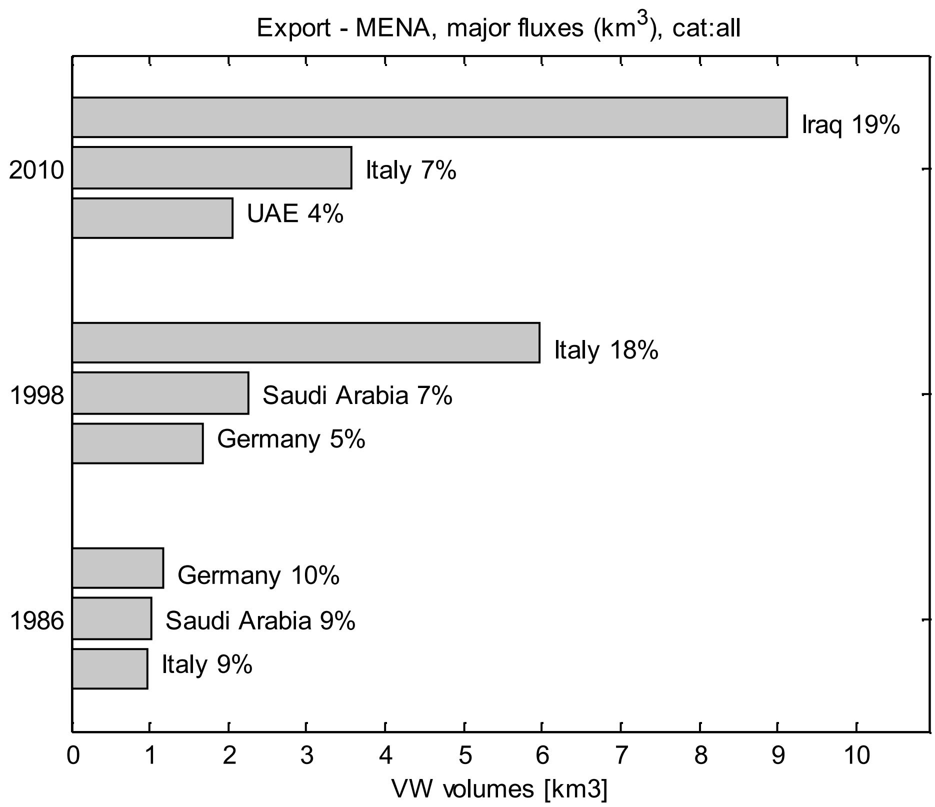
Australia	24.196	74	From low to severe
USA	10.396	41	From low to severe
India	1.692	91	Severe
Pakistan	1.571	94	Severe
Syria	930	88	Severe

Source: Elaboration based on FAO AQUASTAT 2014, Hoekstra and Mekonnen 2011

6.4.4.2 'Export' destinations

Figure 6.23 shows the three major virtual water 'export' trade destinations of the MENA region in the years 1986, 1998 and 2010. The countries are ranked by volume of virtual water 'imported' from the MENA economies via agricultural commodity trade. It is noteworthy to say that the scale of the MENA virtual water 'exports' (<9.5 km^3/yr) is far lower that the scale of virtual water 'imports' (>30 km^3/yr).

Figure 6.23 The MENA virtual water 'export' trade destinations: volumes and percentage shares of total trade (1986-2010)



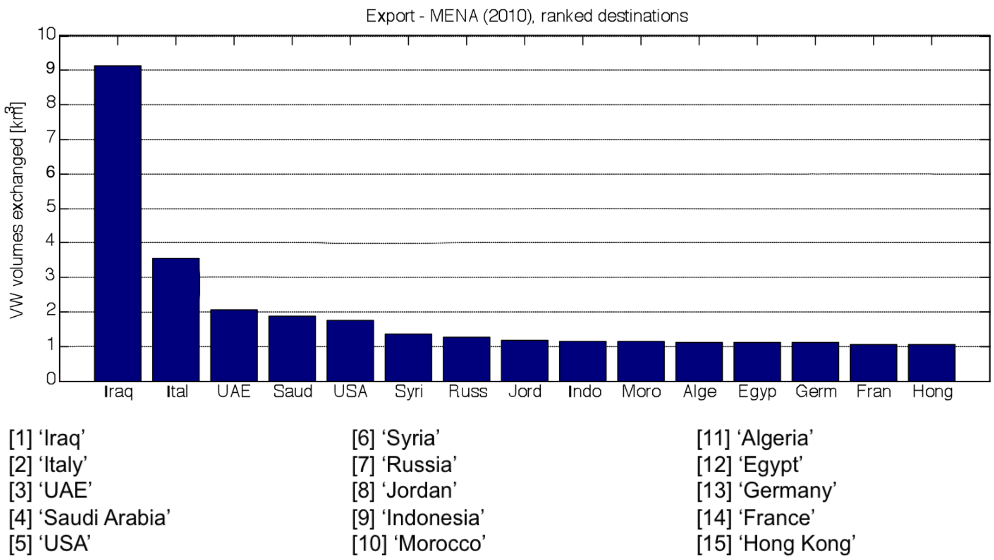
Source: Elaboration based on Tamea et al. 2013 and Carr et al. 2013

In 1986, the main virtual water 'export' trade partners were, besides Saudi Arabia (9% of the MENA total 'exports'), two EU economies, namely Germany (10%) and Italy (9%). In 1998, these three countries were still the top three destinations of MENA 'exports' of virtual water, although with a different country ranking. Italy is ranked as the first virtual water 'export' trade partner in the MENA (18%), followed by Saudi Arabia (7%) and Germany (5%). By 2010, virtual water 'exports' became highly intra-regional, with Iraq showing by far the largest 'inflow' (19% of the MENA total 'exports'), followed by Italy (7%) and UAE (4%).

As shown in Figure 6.24, in 2010, eight of the fifteen main destinations of virtual water 'exports' from the MENA region (accounting for 60% of total 'exports'), are *within* the region. Iraq is by far the largest virtual water 'importer' mainly as a result of its crop imports as well as, although to a much lower extent, lux-foods and animal products. Italy, the second 'export' trade destination, imports mainly crops, as well as the USA. Other MENA virtual water 'export' destinations include the UAE (mainly crops); Syria, Jordan, Morocco (mainly crops, but also animal products); Algeria (mainly lux-foods) and Egypt (crops). Another two EU countries (namely, France and Germany) are also ranked among the main virtual water 'export' destinations.

The MENA 'exports' as 'embedded' in crops is intra-regional to a considerable extent, mainly as a result of the imports from Iraq; whereas 'exports' in animal products and lux-foods are almost entirely intra-regional. Virtual water 'trade' in non-edible commodities is negligible. A differentiation of virtual water 'export' trade destinations of the MENA region by category of traded agricultural commodity is provided in the Appendix C. The main findings of this section are summarised in Table 6.6.

Figure 6.24 The MENA virtual water 'export' trade destinations: volumes (2010)



Source: Elaboration based on Tamea et al. 2013 and Carr et al. 2013

Table 6.6 The MENA virtual water 'trade' partners (1986-2010)[34]

	Top three VW 'trade' partners
Virtual water 'import' trade partners	**2010** – Brazil, USA, Russia **1998** – USA, Australia, Argentina **1986** – USA, Australia, Argentina
Virtual water 'export' trade destinations	**2010** – Iraq, Italy, UAE **1998** – Italy, Saudi Arabia, Germany **1986** – Germany, Saudi Arabia, Italy

Source: Elaboration based on Tamea et al. 2013 and Carr et al. 2013

6.4.5 The MENA countries' dependency on external water resources

This section will seek to answer the fifth sub-question of this chapter, that is:

To what extent have the MENA countries been 'net importers' of virtual water? To what extent are they dependent on virtual water 'imports' to secure their food needs?

In order to answer these questions, first, an assessment of the MENA countries' virtual water 'imports' and 'exports' will be provided. Secondly, the 'net import'

[34] The MENA countries were underlined in order to capture the scope of the virtual water 'exchanges' between the region's economies.

of virtual water per country will be determined. The '*net import'* of virtual water of a country is equal to the 'gross import' of virtual water minus the 'gross export', over a certain period of time. This definition is consistent with that provided by Hoekstra *et al.* (2011)[35]. A positive virtual-water balance indicates a 'net inflow' of virtual water to the country from other countries; whereas a negative balance indicates a 'net outflow' of virtual water.

Secondly, this section will provide an assessment of the MENA countries' dependency on external water resources. The *virtual water dependency of a nation* can be calculated as the ratio between net virtual water 'imports' (virtual water 'imports' minus 're-exports') and water appropriation for agricultural consumption (i.e. the water footprint of consumption of agricultural products). This definition is consistent with Hoekstra *et al.* 2011 (more details on the methodology are provided in the methodology Chapter 4). The indicator reflects the level to which a country relies on external water resources, in percentage terms. High values indicate high dependency on virtual water 'imports'; low values, on the contrary, indicate higher water self-sufficiency.

6.4.5.1 Virtual water 'net imports'

Figure 6.25 shows the total volumes of virtual water 'imported' and 'exported' by the MENA countries as a result of international trade in agricultural commodities, averaged over the period 1986-2010. These volumes include the virtual water 'exchanged' both between the MENA countries and with non-MENA countries. The average volume of 'imported' virtual water exceeds 'exports' in all the MENA countries. The largest total volumes of 'imported' virtual water in the region are observed in Egypt, Iran and Saudi Arabia, followed by Algeria and Turkey. Virtual water 'imports' in these countries range roughly between 27 and 14 km^3 per year and are mainly 'embedded' in *crops*.

[35] Hoekstra *et al.* (2011) use the term *virtual water balance of a country* when referring to the net virtual water 'imports' of a given country.

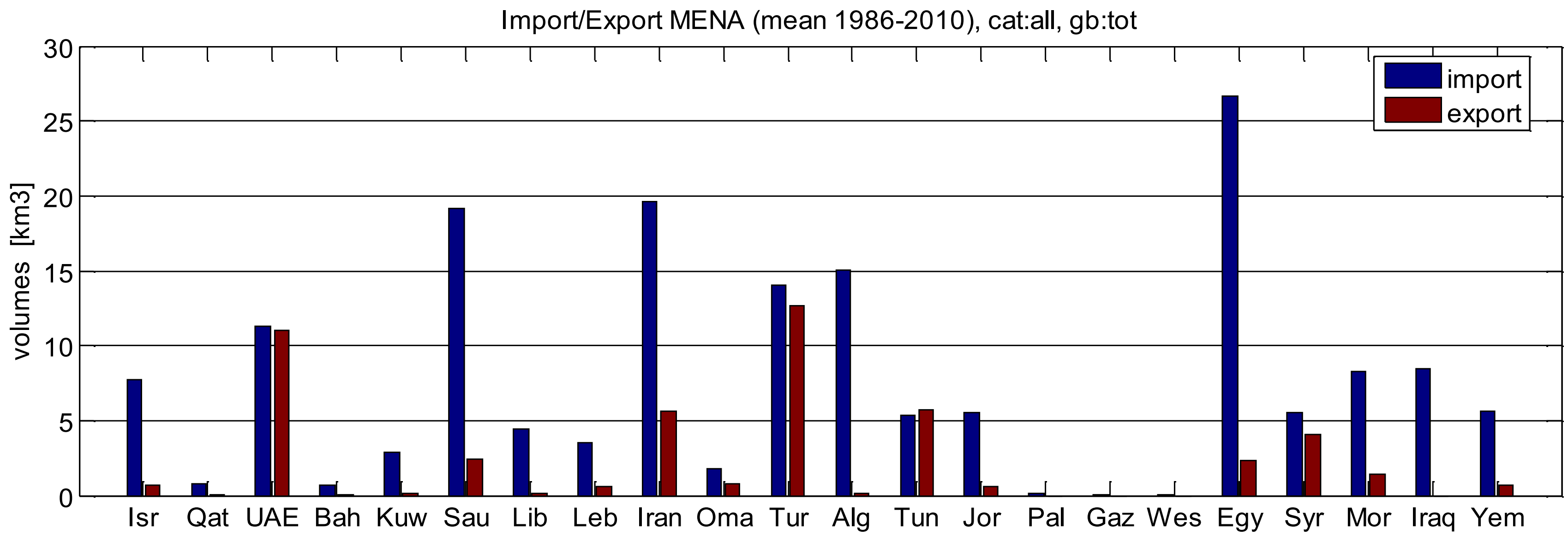
Egypt and Saudi Arabia are among the top fifteen importing economies of agricultural commodities and food commodities at the global level (WTO 2013). Egypt is the largest 'importer' of virtual water as 'embedded' in crops – mainly wheat – in the region. As previously stated, this country has been in fact the world's largest importer of wheat since the mid 2000s. Saudi Arabia's 'import' of virtual water is mainly related to the import of cereals (especially barley) whose net import accounts for 80% of total national consumption (Ianchovichina *et al.* 2012). Saudi Arabia has been the first importer of barley in the world since the early 1990s (FAOSTAT 2014). Egypt and Saudi Arabia are also the largest 'importers' of virtual water in animal products in the region. Virtual water 'imports' by Algeria and Turkey are mainly associated with the import of wheat. The two countries are among the largest importers of wheat in the world (WTO 2013; FAOSTAT 2014). Turkey is also the largest 'importer' of virtual water in *non*-edible agricultural commodities; Algeria is the largest 'importer' of virtual water in lux-foods. Over the same period, virtual water 'imports' averaged about 11.30 km^3/yr in the UAE; 8.45 km^3/yr in Iraq[36]; 8.30 km^3/yr in Morocco; and 7.71 km^3/yr in Israel. These countries' virtual water 'imports' are mainly associated with crops and lux-foods. In the rest of the MENA countries virtual water 'imports' are below 6 km^3.

As shown in Figure 6.25, the highest average volumes virtual water 'exports' are observed in Turkey (12.69 km^3/yr, mainly 'embedded' in crops but also lux-foods) and the UAE (11 km^3/yr). The equivalence of the UAE's 'imports' and 'exports' in virtual water seems to suggest a re-export of imported goods that, however, was not possible to be tracked due to limitations in the available datasets. In Tunisia, Iran and Syria, virtual water 'exports' range roughly between 4 and 6 km^3/yr and are mainly associated with the export of crops. In the rest of the MENA countries, the volumes of virtual water 'exports' are negligible (<2.5 km^3/yr).

[36] It is important to highlight that data referring to virtual water 'trade' in Iraq were affected by the fact that the country reported no exports of agricultural products over the period considered (1986-2010).

[37] Virtual water 'net import' were not calculated for Iraq as the country reports no exports of agricultural commodities for the period considered.

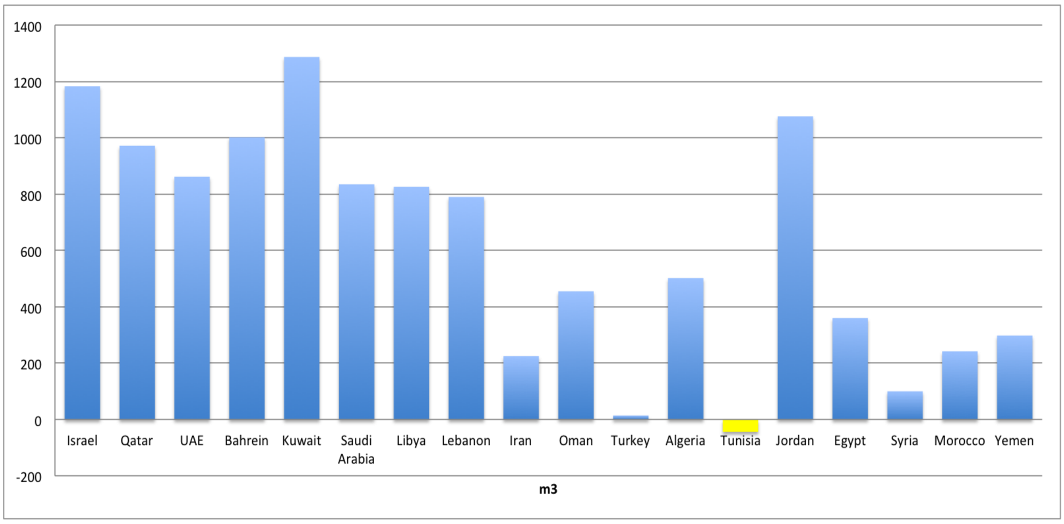
Figure 6.25 Average virtual water 'imports' and 'exports' total cubic kilometres per year in the MENA countries (1986-2010), sorted by decreasing human development index (HDI)



Source: Elaboration based on Tamea et al. 2013 and Carr et al. 2013

By subtracting average ‘gross imports’ to the ‘gross exports’, virtual water net ‘imports’ can be obtained. As shown in Figure 6.26, all the MENA countries show positive virtual water ‘balances’ per capita, which correspond to ‘net inflows’ of virtual water from other countries. The only exception is Tunisia, where the average virtual water ‘outflows’ is, however, only 0.37 km^3 per year. Countries are ranked according to their Human Development Index to show that the most diversified and adaptive economies in the region (left side of the graph) generally show relatively higher virtual water ‘net imports’ than the less diversified economies in the region. Jordan is the exception, showing per capita virtual water ‘net imports’ comparable with Israel and the oil-enriched countries in the region.

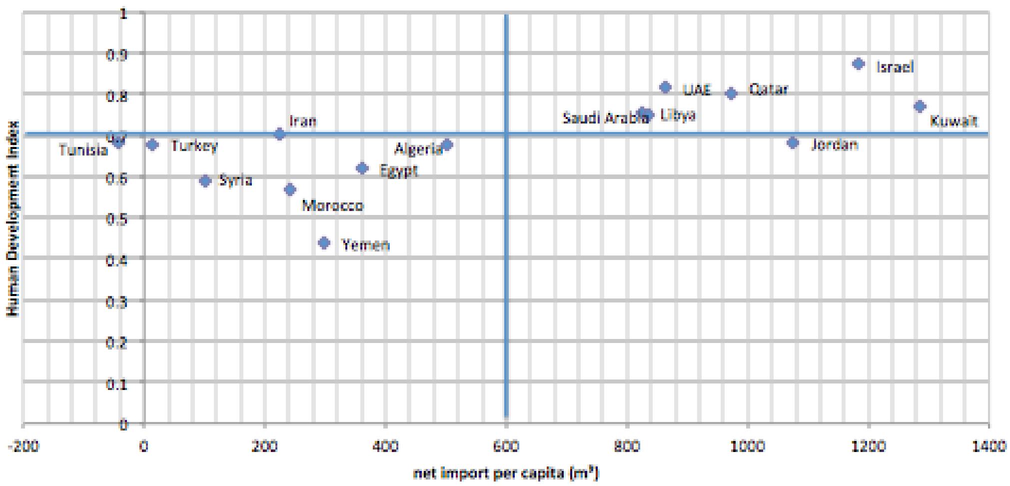
Figure 6.26 Average virtual water ‘net imports’ (cubic meters per capita per year) in the MENA countries (1986-2010), sorted by decreasing human development index (HDI)[37]



Source: Elaboration based on Tamea et al. 2013 and Carr et al. 2013

The correlation between virtual water ‘net imports’ and socio-economic ‘adaptiveness’ is further demonstrated in Figure 6.27. The line parallel to the x-axis identifies different levels of Human Development Index: very high and high (above the line); medium and low (below the line). The upper right quadrant thus identifies a cluster of diversified economies in the region showing high virtual water ‘net imports’ per capita. Jordan is the only country with high virtual water ‘net imports’ per capita and medium HDI (right lower quadrant). Tunisia, the only country on the left of the y-axis, is the only virtual water ‘net exporter’ in the region, although to a very small extent. The next section will show that socio-economic development and reliance on trade are strongly correlated with food security in the MENA countries.

Figure 6.27 Correlation between average virtual water ‘net imports’ per capita and HDI in the MENA countries (1986-2010)

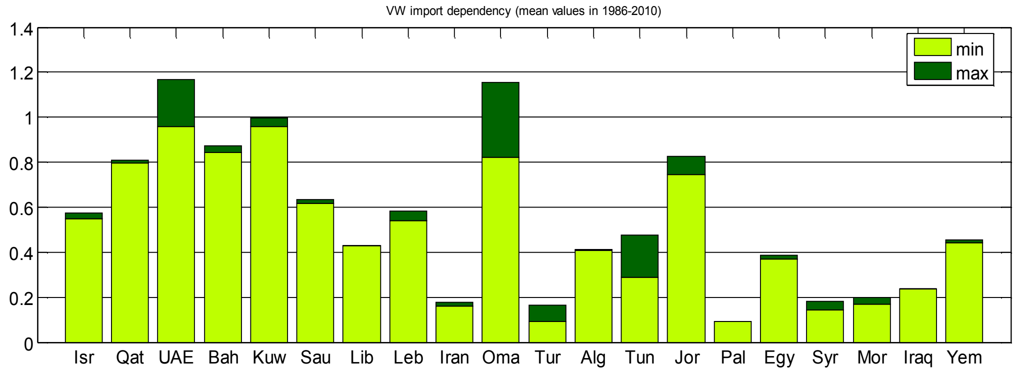


Source: Elaboration based on Tamea et al. 2013; Carr et al. 2013; UNDP 2013

6.4.5.2 Virtual food-water ‘import’ dependency in the MENA economies

In order to understand the extent to which the MENA economies depend on virtual water ‘imports’ to secure their food-related water needs, a *virtual food-water ‘import’ dependency indicator* (D) was developed for each MENA economy. This indicator is defined as the ratio between virtual water ‘imports’ minus ‘re-exports’ over the water footprint of consumption of a given country. Figure 6.28 identifies both the minimum and maximum values of the virtual food-water ‘import’ dependency, averaged over the period 1986-2010. Minimum values of dependency (yellow) are obtained by assuming that all virtual water ‘exports’ go to re-export; maximum values of dependency (green) are obtained, on the contrary, by assuming that there is no re-export at all. By computing minimum and maximum values of dependency, it was possible to overcome data limitations, which does not allow tracking of re-exported commodities in the countries of interest (further details can be found in the methodology Chapter 4).

Figure 6.28 Minimum and maximum values of the virtual food-water 'import' dependency (*D*) in the MENA economies (average 1986-2010), sorted by decreasing human development index (HDI)



Source: Elaboration based on Tamea et al. 2013 and Carr et al. 2013

As shown in Figure 6.28, all the MENA countries have been, on average, highly dependent on the 'import' of virtual water to secure their food needs, over the period considered. Virtual water 'import' dependency has limited variability due to the small values of virtual water 'exports' reported by each country. Countries are ranked according to HDI to show that the dependency on food-water 'imports' is relatively higher in the more diversified and adaptive countries in the region, such as the United Arab Emirates, Kuwait, Bahrain and Qatar (all above *D*=80%). Oman shows a high dependency (intermediate value around 100%) with large variability, due to significant exports in wheat flour, vegetable oils and dry milk. Countries with considerable agricultural productions and relatively higher water endowments compared with other MENA economies (such as, Iran and Turkey) show low dependency values (<20%). Table 6.7 summarises the main findings of this section.

Table 6.7 Virtual food-water 'import' dependency levels in the MENA countries (average, 1986-2010)

Very high (>100%)	**High** (50-100%)	**Medium** (30-50%)	**Low** (0-30%)
UAE Oman	Israel Qatar Bahrain Kuwait Saudi Arabia Lebanon Jordan	Libya Algeria Tunisia Egypt Yemen	Iran Turkey Palestine Syria Morocco Iraq

Source: Elaboration based on Tamea et al. 2013 and Carr et al. 2013

A correlation between food security, economic diversification and adaptiveness (very high/high HDI), as well as high dependency on virtual water 'imports' and mineral resource endowments, has been found (Table 6.8). The only exceptions are Iran (large agricultural production and a net import of food of 30% of total consumption[38]) and Turkey (large agricultural production and virtual water 'imports' which almost equal virtual water 'exports'). Some of the most water-dependent countries in the region (namely, Saudi Arabia, Jordan, Israel and Kuwait) are also the most green and blue water scarce, as demonstrated in Chapter 5. Despite very low water endowments, these countries can all be considered *food secure* or *moderately food secure* in the case of Jordan, which shows in fact a medium level of socio-economic diversification (medium HDI). Yemen is the most vulnerable country in the region due to its poor first-resource (mineral and water) resource endowments and low second-order resources (HDI). Undernourishment in Yemen is also far higher than in the rest of the MENA countries, as shown in Table 6.8.

[38] Ianchovicina *et al.* 2012

Table 6.8 Mineral resource endowments, HDI, virtual water 'import' dependency and food security in the MENA economies

	Mineral resource rich[39]	Mineral resource poor[40]	HDI[41]	VW 'import' dependency[42]	Food security[43]	Undernourished population[44]
UAE	√		Very high	High	Food secure	N/A
Israel		√	Very high	High	Food secure	5%
Tunisia		√	High	Medium	Moderately food insecure	5%
Lebanon		√	High	High	Moderately food insecure	5%
Bahrain	√		High	High	Food secure	N/A
Syria	√		Medium	Low	Moderately food insecure	5%
Qatar	√		Very high	High	Food secure	N/A
Kuwait	√		High	High	Food secure	7.4%
Libya	√		High	Medium	Moderately food insecure	5%
Iran	√		High	Low	Food secure	5.1%
Saudi Arabia	√		High	High	Food secure	5%
Morocco		√	Medium	Low	Moderately food insecure	6%
Jordan		√	Medium	High	Moderately food insecure	6.3%
Turkey		√	High	Low	Food secure	5%
Algeria	√		High	Medium	Moderately food insecure	5.4%
Egypt		√	Medium	Medium	Moderately food insecure	5%
Yemen		√	Low	Medium	Food insecure	31%

Source: Elaboration based on Breisinger et al. 2010; Woertz 2011; UNDP 2013; Tamea et al. 2013; Carr et al. 2013; World Bank 2014

[39] Based on Breisinger *et al.* 2010. Food security is calculated on the basis of the ratio of food imports on total exports, food production per capita, GNI per capita and the GHI provided by IFPRI.

[40] *ibidem.*

[41] UNDP 2013.

[42] Based on Tamea *et al.* 2013 and Carr et al. 2013.

[43] Based on Breisinger *et al.* 2010; Woertz 2011.

[44] Undernourishment is measured as the percentage of the population whose food intake is insufficient to meet dietary energy requirements continuously. Data shown in the Table refer to the average of the period 1990-2011 (own calculation based on World Bank 2014).

These findings have substantial implications for policy-making. A first implication is that virtual water analysis has the potential to enable policy makers to reform the hitherto prevailing water security and food security concepts. Another implication is that the capacities associated with socio-economic diversification as well as the ability to optimise opportunity costs of local water resources determines the direction of virtual water 'trade', rather than water endowments. The MENA case shows that socio-economic development is a pre-condition for water and food security. A third implication regard the risk of "undersecuritisation" (Warner 2003: 130), that is the risk that reliance on virtual water 'trade' is used by policy makers not to switch to more reasonable and sustainable water management strategies. The next chapter will distinguish green and blue water resources 'embedded' in agricultural commodity trade. This distinction is essential to inform and optimise water policy decisions.

To sum up, this section has demonstrated that the dependency on virtual water 'imports' is generally constrained by a given country's income as well as its capacity to engage in trade. This relationship explains the fact that the less adaptive economies in the MENA generally show lower dependencies on external water resources than better-off countries. This result is consistent with the global assessment developed by Liu *et al.* (2009). It can be argued that strengthening economically the poorly diversified countries in the region is a pre-requisite for developing a virtual water "strategy" that has the potential to effectively enable them to overcome food insecurity and relieve the pressure on local water resources.

6.5 Conclusions

The overarching aim of this chapter has been to investigate the extent to which the MENA region has relied on virtual water 'trade' in agricultural products to secure the requirements its populations. The analysis presented is original in that it has provided the first *comprehensive* assessment of virtual water 'trade' in the MENA region as a whole. This aim has been reached by exploring the structure and evolution of 'trade' in virtual water implicit in agricultural commodity trade in the period 1986-2010.

The MENA has, after the largely integrated EU, the second highest virtual water 'import' in the world and faces rapid population growth and change in dietary habits. These two factors have driven, respectively, the increase in the region's water footprint of consumption of agricultural products and virtual water 'imports'. Over the time-span considered, virtual water 'imports' in the MENA have more than doubled. Their increase has been more than proportional to population growth in the area, facilitated by a downward trend in food commodity prices. Food products account by far for the largest share of virtual water 'flows'. More specifically, crops and lux-foods are the main categories of agricultural products associated with virtual water 'imports'.

The chapter has also shown that in all the MENA economies, the 'gross import' of virtual water exceeds the 'gross export'. The only exception is Tunisia although to a very small extent. The chapter also shown that most the external water resources accessed through global trade in agricultural commodities originate *outside* the MENA area, but not always come from water-secure countries. Moreover, it was revealed that the 'export' of virtual water from the MENA is quite regionalised. Iraq, UAE, Saudi Arabia, Syria, Jordan, Morocco, Algeria, and Egypt are among the leading fifteen virtual water 'export' trade destinations of the MENA region. Finally, a correlation has been found between high virtual water 'import' dependency, socio-economic diversification and adaptiveness, food security and mineral resource endowments.

The study argues that water insecurity has its roots in water physical scarcity, but it emerges in contexts of poor second order resources, i.e. the social, economic and political factors necessary for a society to positively adapt to change. All the MENA countries experience water scarcity in terms of the resource endowments, but they are differently exposed to the risk of water insecurity, which occurs if water scarcity exists in conjunction with a lack of second order resources – i.e. the country's *social adaptive capacity*. High or low levels of the second order resources therefore determine the vulnerability to the risk of water insecurity.

The 2007-2008 spikes in food prices witnessed the vulnerability of large food importers, such as the MENA economies, to the oscillations and distortions of global markets. Over these years, the region experienced the difficult combination of sudden restrictions by the world's exporting countries, in the form of bans and quotas; soaring food bills, which results in an increased pressure on public finance and consumers' expenditure on food. These factors spurred civil unrests and turmoil in some of the region's countries. A recent study forecasts an increase in the region's food import bill from 61.4 to almost 93 US$ billion by the year 2020 (Al Masah Capital Limited 2012). These changing conditions for importing food (and virtual water) are likely to affect the most the less diversified economies in the region, prevent their capacity to achieve food security the way they have managed to do so over the past decades.

Given the increasing pressure on local water resources greater attention should be paid to the water resources management in MENA countries, but also to the trade agreements and exchanges that shift the water pressure *outside* the area. The water dependency should be recognized at the policy level, while the increasing water pressure needs to be urgently faced to avoid exacerbation of a problematic socioeconomic and environmental situation triggered by food-water insecurity. It can be argued that strengthening economically the poorly diversified countries in the region is a pre-requisite for developing a virtual water "strategy" that has the potential to effectively enable them to overcome food insecurity and relieve the pressure on local water resources.

The following chapter will explore virtual water 'trade' in the MENA region by distinguishing between the two sources of agricultural water 'embedded' in traded commodities: green and blue water resources. In pursuing this aim, the chapter will not only seek to overcome one of the main limitations of previous analyses, but also to provide policy-relevant recommendations and insights.

7. Green and Blue Virtual Water 'Trade' in the Middle East and North African region

7.1 Introduction

The aim of this chapter is twofold. First, to identify the sources of water 'embedded' in the MENA virtual water 'trade' in order to discuss the role and significance of international agricultural trade, which entails an invisible 'exchange' of water resources at the global level. Secondly, the chapter will shed light on the *invisible* role that *green* (soil) water plays in underpinning food security in the MENA region, as opposed to surface and groundwater bodies (*blue* water), that mainly supplement green water in irrigated agricultural systems.

Green water is the water resource consumed by rainfed agricultural systems. It supports the largest share of food production globally. Global food security is thus very reliant on this source of water. Green water will continue to provide the main source for crop and livestock production in the future. There is still a significant potential to improve green water management and practices and to increase yields (Falkenmark and Rockström 2006; IMWI 2007; Oweis and Hachum 2009; Fader *et al.* 2011; Hoekstra and Mekonnen 2012). Green water has a low opportunity cost compared with blue water, as it cannot be allocated to other economic uses. On the other hand, it does have an important role in sustaining the ecosystem services (De Fraiture *et al.* 2004). The use of green water for agricultural production is relatively environmentally benign compared with the use of blue water (Aldaya *et al.* 2010a).

Green water is a very important source of water in drought-prone areas, such as the MENA region, where it sustains dryland (rainfed) farming and associated livestock production (Chatterton and Chatterton 1996). In the MENA economies, the extent to which green water underpins local food production has neither been sufficiently recognised by policy makers nor taken into account in water resource planning (Chatterton and Chatterton 1996; Allan 2001). It is important to highlight the importance of green water in the region and the complementary role of blue water resources. These blue water resources are everywhere over-abstracted and their ecosystem services have been very negatively impacted.

This chapter provides a comprehensive and original analysis of the green and blue water 'flows' that have entered and exited the MENA region as 'embedded' water in internationally traded agricultural commodities over the past two and a half decades. As demonstrated in the previous chapter (Chapter 6), during the study period the importation of food commodities grew considerably. They almost tripled and there was a proportional increase in virtual water 'imports'.

The analysis in this chapter focuses on four categories of agricultural commodities: crops (including cereals, fruits and vegetables), animal products (including meat and diary), lux-foods (i.e. high-value foods such as spices, tea, coffee and sugars) and non-edible agricultural commodities (including plant fibres, tobacco and non-edible oils). These are the same categories deployed in Chapter 5. The two analyses are consistent and also complementary (more details on this aspect are provided in the methodology Chapter 4).

The analysis will show that the largest share of the virtual water 'flowing' to the MENA political economies is 'embedded' in traded commodities is *green water*, as the region's trade partners mainly produce under rainfed conditions. It will be shown that the reliance on blue water resources for producing agricultural commodities for export is relatively higher in the MENA economies than in their virtual water 'trade' partners. Highlighting the contribution of blue water in virtual water 'exports' from the water-deficit MENA countries is important in that it reveals the amount of high-opportunity cost freshwater that is first abstracted from local surface and groundwater bodies that then exit the region.

Six main aims are addressed. First, the evolution of blue and green virtual water 'trade' in agricultural commodities over the past three decades has been examined. Secondly, the extent to which the MENA countries have 'exchanged' green and blue virtual water within the region and with the rest of the world has been analysed. Thirdly, the region's 'net import' of green and blue virtual water and the evident dependency on external water resources has been assessed. Fourthly, the 'flows' of green and blue virtual water by category of traded agricultural product have been differentiated. Fifthly, the main virtual water 'import' and 'export' of the trade partners in green and blue water of the MENA region have been identified and the impacts of commodity trade on local water resources have been highlighted. Finally, the MENA virtual water 'trade' in four key commodities (namely, cereals, wheat, meat and cotton) have been analysed.

Virtual water 'trade' in the MENA has been analysed in a number of studies (Jobson 1999; Wichelns 2001; Yang and Zehnder 2002; Zeitoun *et al.* 2008; El Sadek 2010; Faramarzi *et al.* 2010; Soltani 2013). The analysis carried out in the chapter makes an original contribution to the field as none of these other studies have focused on MENA virtual water 'trade' and how the different sources of water have been 'embedded' in traded commodities. Moreover, none of these studies have examined the historical dynamics of virtual water 'trade' in the region. This shows that it is important to distinguish the two types of water – green and blue – in virtual water 'trade' in order to gain policy relevant insights and provide recommendations to water users and policy makers in the region. The need to unlock the full potential of green water in order to raise the productivity of dryland farming will also be emphasised. The next section re-iterates the overarching research question and the sub-questions identified in the introductory chapters. The relevant hypotheses to be tested will also be presented.

7.1.1 Research questions and hypotheses

The first analytical chapter (Chapter 5) provided an assessment of food-water resource availability in the MENA region, addressing the first subsidiary question of the study (that is, *"To what extent can local water resources meet the food-water requirements of the MENA political economies?"*).

The assessment has been original in that it included the *full* range water resources types available for food production, that is not only the water contained in surface and groundwater bodies, but also soil (green) water, available in the MENA countries. It has been shown that green water has been an important source of agricultural water in a number of countries in the region – namely, Iran, Turkey and Syria in the Near East; and in Morocco, Tunisia and Algeria in North Africa, Green water has underpinned long established, but operationally sub-optimal, dryland winter farming and grazing (Chatterton and Chatterton 1996; Allan 2001)[45]. Green water has never been included in national water budgets in analyses of the MENA region. Its utilisation has generally been below its potential. It is argued here that accounting for green water can much better inform water resources management and planning processes. The chapter has also provided an assessment of food-water scarcity in the region's countries. It has been demonstrated that, with the exception of Turkey, *all* the MENA countries face food-water scarcity, although to different extents, as the water available is never sufficient to meet the country-specific water requirements for local food security. Water scarcity is particularly severe in Saudi Arabia, Jordan, Yemen, Israel, Kuwait and the other GCC economies.

In the second analytical chapter (Chapter 6), the extent to which the MENA political economies depend on virtual water 'imports' to secure their population's food needs was examined. The second subsidiary question was addressed – that is. "*What has been the role of international trade in meeting the water*

[45] Dryland farming can be defined as rainfed crop production in water scarce areas, characterised by high levels of evapotranspiration, combined with erratic and limited rainfall, which is however sufficient to sustain crop growth (Pereira *et al.* 2002). More details on this type of rainfed farming are provided in Section 7.4.2.2.

requirements of the MENA economies? And, more specifically: *To what extent have the MENA countries relied on virtual water 'trade' to secure their food-water needs?".*

Chapter 6 provided a comprehensive assessment of the MENA virtual water 'trade' over the past two and a half decades. It analysed the temporal dynamics and evolution of commodity trade and its virtual water 'content'. It was shown that population growth and changes in dietary preferences have driven, respectively, an increase in the MENA water footprint of agricultural production as well as in virtual water 'imports'. These 'imports' have been analysed on a per capita basis and have been shown to be the second highest in the world after the largely integrated EU. It was shown that virtual water 'imports' originate mainly outside the region; but that virtual water 'exports' have a substantial intra-regional component. The role of food commodities, especially crops, in intra-MENA virtual water 'trade' were also analysed.

By assessing virtual water security as dependency ratios, it has been possible to compare how MENA economies depend on virtual water 'imports' in order to secure their food needs. A correlation has been identified relating virtual water 'import' dependency, to socio-economic diversification and adaptiveness, as well as to food security and mineral resource endowments. Finally, it has been shown that the most water-deficit economies in the region (namely, Saudi Arabia, Jordan, Israel and Kuwait) are *food secure* as second-order (socio-economic) resources have enabled them to cope with first-order resource (water) deficits through the 'import' of virtual water from the global system.

The overarching aim of the present chapter is to investigate the contribution of the different sources of agricultural water to the virtual water 'trade' in agricultural commodities of the MENA political economies'. More, specifically the chapter will provide a comprehensive analysis of the extent to which green and blue water resources are 'embedded' in the MENA import and export of agricultural goods. As argued in previous chapters (Chapter 3 "Background", and Chapter 5 "Water scarcity in the MENA"), it is essential to distinguish between green and blue virtual water as these two sources have very different characteristics, which are reflected in their opportunity costs and in the externalities associated with their use. It is argued in this chapter that using (and 'trading') green water is often much more sustainable compared with blue water usage in agriculture.

The question to be addressed in this chapter is the third subsidiary research question of the study, that is: ***To what extent have green and blue water resources underpinned the MENA virtual water 'trade'?*** Four interrelated sub-questions have been identified.

Sub-question 3.1 *How has green and blue virtual water 'trade' in agricultural commodities evolved over the past three decades, both globally and in the MENA region?*

Hypothesis. The study hypothesises that green water is the main source of virtual water 'embedded' in agricultural commodity trade, both at the global level and in the MENA. It also hypothesises that blue water accounts for a substantial proportion of the virtual water 'exported' by the MENA countries, as their reliance on this source of water is relatively higher than that of their virtual water 'import' trade partners. It will be shown that the blue water component is higher in virtual water 'exports' in crops and lux-foods compared with the 'imports' of the same products, and blue water is also the predominant source of water 'embedded' in the export of non-edible commodities.

Sub-question 3.2 *What has been the structure of green and blue virtual water 'trade' in the MENA economies over the past three decades? That is, to what extent have the MENA countries 'exchanged' green and blue virtual water between themselves and with the rest of the world?*

Hypothesis. The chapter hypotheses that green water green water dominates both extra-regional and intra-regional 'trade' in virtual water. It also hypothesizes that the blue water component is relatively more important in virtual water 'exports' and intra-regional virtual water 'trade', compared with its role in 'imports'.

Sub-question 3.3 *Which have been the main green and blue virtual water import 'trade' partners of the MENA economies?*

Hypothesis. It is hypothesised that the main virtual water 'import' trade partners of the MENA region engage in crop and livestock production under rainfed conditions and that, as a result, the virtual water 'export' from these countries is mainly associated with green water. It is also hypothesised that the blue virtual water 'imported' by the MENA economies originates, to a considerable extent, from *within* the region and often takes place (both intra-regionally and extra-regionally) in circumstances of local blue water scarcity.

Sub-question 3.4 *To what extent has the MENA 'exported' virtual water in the different types of agricultural commodities? Which have been the main "channels" of virtual water 'outflows' from the region's economies?*

Hypothesis. It is hypothesised that crops dominate both 'exports' associated with blue and green water from the MENA to the rest of the world. It is also hypothesised that lux-foods exports from MENA economies account for a significant share of green virtual water 'exports', whereas non-edible commodities play a significant role in determining blue virtual water 'outflows'.

Sub-question 3.5 *To what extent have the MENA countries been 'net importers' of green and blue virtual water?*

Hypothesis. It is hypothesised that green water dominates the virtual water 'imports' at the country level. It is also hypothesised that the relative importance of blue water in virtual water 'exports' is more significant than in virtual water 'imports', as the region's economies rely relatively more on irrigated agriculture than the world's virtual water 'exporting' economies.

7.1.2 Structure

The chapter has six main sections. The first section presents the overall aims of the chapter and has presented the main research questions and hypotheses. The next section provides a re-appraisal of the concept of virtual water 'trade' in green and in blue water, and illustrates the main arguments of the chapter. The third and fourth sections present the results of the analysis. The chapter concludes by discussing the main findings of the research and draws some conclusions.

7.2 The importance of differentiating green and blue water resources

The aim of this section is to briefly re-appraise the concepts of green and blue water, introducing the analysis that follows. The aim of the chapter is to investigate the green and blue virtual water 'embedded' in the MENA virtual water 'imports' and 'exports' implicit in trade in agricultural commodities in order to provide policy-relevant insights to water users and decision makers in the region. The evidence will also be used to assess the sustainability of the virtual water 'trade' 'solution' for the region.

Not all water is equal. Water resources differ in terms of origin, relative scarcity, mobility, possible allocation and opportunity costs. For policy purposes, it is especially important to distinguish between two different types of water – which, for ease of communication, are referred to as *blue* and *green* water. The term *blue water* refers to water stored in lakes, rivers, reservoirs, ponds and aquifers (Rockström *et al.* 1999). G*reen water* is "the return flow of water to the atmosphere as evapotranspiration, which includes a productive role in the biosphere - as transpiration, and a non-productive biospheric role – as direct evaporation from the surface of soils, lakes, ponds, and from water intercepted by canopies (Falkenmark 1995; Yang *et al.* 2006).

Blue water can be diverted to irrigate crops as a supplement to rainfall; green water sustains croplands but also other terrestrial systems such as forests, woodlands, and wetlands, which provide food, raw material and genetic resources and are also responsible for climate regulation, carbon sequestration and waste decomposition. Both green and blue water are sources of food-water (Allan 2013a, 2013b). Green and blue water are also the sources of non-edible food commodities, such as the fibres used in textiles. Trade in cotton has determined, over the period 1997-2001, about 13% of virtual water 'trade' at the global level (own calculation based on Chapagain and Hoekstra 2004 and Chapagain *et al.* 2005b). The analysis in this chapter focuses on food commodities (also distinguishing between crops, animal products and high-value food products, hereby referred to as *lux-foods*), but also include non-edible agricultural commodities. It will be shown that non-edible commodities are reliant on *blue* water resources for their production to a much larger extent than food products.

Blue and green water resources differ in many respects, and their ratio varies substantially over time and space. Originating from rainfall, green water cannot be moved and in general is *not* explicitly valued by users. It can be argued, however, that the price for agricultural land reflects fertility and peculiar climatic conditions, including green water availability (Antonelli *et al.* 2012). Conversely, blue water can be abstracted, pumped, stored, treated, distributed, collected, and recycled. Normally, providing supplies is *costly,* as it requires infrastructure. Green water supports human livelihoods through rainfed crop production as well as ecosystem services, and faces no major competition from other domestic or industrial uses. Therefore, it has a low opportunity cost. Blue water is different. It has the highest economic potential.

Global food production relies mainly on green water, as the main food producing and exporting economies in the world operate in rainfed systems (Fader *et al.* 2011; Konar *et al.* 2012). Green water is also the main source of agricultural water in the MENA region. As shown in Chapter 3, the percentage of rainfed agriculture in farmed lands stands at 75% (AQUASTAT 2012). At the global level, rainfed agriculture exhibits very sub-optimal levels of efficiency. Rainfed cereal yield for instance, is about 2.2 metric tons per hectare, whereas irrigated tracts – both supplementary and wholly irrigated – record yields of 3.4 metric tons per hectare (Rosegrant *et al.* 2002). The need to boost productivity in rainfed farming through investments has been highlighted (de Fraiture *et al.* 2009).

Inefficiency in rainfed farming is mainly due to land degradation and declining soil fertility, which results in high levels of evaporation and runoff, as well as to inadequate water management practices (IMWI 2010). In these contexts, there are significant opportunities to develop agricultural output and water productivity while avoiding irrigation lock-in and the risks of over-allocating blue water (Gilmont *et al.* 2012). It has been suggested that by unlocking the potential of green water, the challenge of feeding future populations *sustainably* can be met (Falkenmark and Rockström 2006; CAWMA 2007).

Green water also dominates virtual water 'flows' at the global level. Traded agricultural commodities are mainly produced on rainfed farms (Yang *et al.* 2006; Fader *et al.* 2011; Hoekstra and Mekonnen 2012). It has been noticed that virtual water 'exporting' countries 'export' a proportion of green water that is higher than the proportion of green water, which stays in the country for domestic production[46] (Liu *et al.* 2009). This outcome suggests that holding other factors constant, trading green virtual water is more efficient than 'trading' blue virtual water (Yang *et al.* 2006; Chapagain *et al.* 2006). The reason is that the blue water allocated to irrigated agriculture yields the *lowest* economic value among all alternative uses and it is often associated with significant environmental externalities − such as water logging, salinisation, soil degradation (Zehnder *et al.* 2003). In practice, green water cannot be over-allocated. Irrigated systems tend, on the other hand, to over-allocation (Allan 2013a). This is particularly the case in the MENA region, where surface and groundwater bodies are already under major strain, as detailed in Chapter 2. The use of green water in agriculture, however, causes a loss of natural environments as well as soil quality degradation as a consequence of the use of fertilizers and pesticides (Rosegrant *et al.* 2002; De Fraiture *et al.* 2004; Aldaya *et al.* 2010a).

As argued by Allan (2001), the water stress of an economy can be appraised by looking at its food imports statistics, because agricultural production is the most water-intensive economic activity. This study argues that it is important to

[46] An exception is Thailand as it exports mainly rice, whose production requires irrigation (Liu *et al.* 2009).

differentiate blue and green water resources in the light of the different characteristics, opportunity costs and externalities associated with their use. It also argues that by importing goods, a water-deficit country can potentially free up the water inputs that would have been needed to produce the same goods domestically. Virtual water 'imports' can be defined as an externalisation of water use to other countries. The importing economies benefit significantly. The 'import' of virtual water potentially enables the blue water in the importing economies be re-allocated to uses yielding much 'more value per drop' than irrigated agriculture. Virtual water 'trade', however, also brings "losers". This is the case of water-scarce countries 'exporting' blue-water sourced agricultural products, such as a number of the major exporters of cotton in the world.

The importance of considering the role played by green water in global food and water security has started to be recognised in the early 2000s (Allan 2001; Rockström 2001; Falkenmark and Rockström 2004, 2006; IMWI 2007; Rockström *et al.* 2007; Aldaya *et al.* 2008; Rost *et al.* 2008; Yang and Zehnder 2008; Liu *et al.* 2009; Rockström *et al.* 2009; Rost *et al.* 2009; Aldaya *et al.* 2010a; Hoff *et al.* 2010; Rockström *et al.* 2010; Allan 2011; Gerten *et al.* 2011; Allan 2013a). A number of studies have incorporated the notions of green and blue water by differentiating the two sources in virtual water 'flows' for different crops and aggregations of agricultural goods (Hoekstra and Hung 2002; Yang *et al.* 2006; Liu *et al.* 2009; Aldaya *et al.* 2010a; Hanasaki *et al.* 2010; Mekonnen and Hoekstra 2010a, 2010b; Fader *et al.* 2011; Mekonnen and Hoekstra 2011b; Hoekstra and Mekonnen 2012; Konar *et al.* 2012; Antonelli *et al.* 2012).

Green and blue virtual water 'trade' is still a relatively unexplored field of enquiry, especially in the MENA region. By differentiating green and blue virtual water 'flows', the study seeks to overcome a major limitation of existing studies on virtual water 'trade' in some of the MENA economies (among others, Jobson 1999; Wichelns 2001; Yang and Zehnder 2002; Elhadj 2004; El Sadek 2010; Faramarzi *et al.* 2010; Soltani 2013). Only studies have included both sources of agricultural water in the MENA. These studies are Chahed *et al.* (2008), which provides an assessment of virtual water 'trade' in Tunisia; and Faramarzi *et al.*

(2009), which provides and estimate of water availability in Iran. The third is the study of virtual water 'flows' within the Nile Basin and in and out of the Basin. (Zeitoun *et al.* 2010). Building on these studies, this chapter aims to investigate green and blue virtual water 'flows' that have entered and exited the MENA economies over the past two and a half decades. Policy-relevant insights will contribute to *widening* the approach of the region's water resource policy makers, which still mainly have a *blue* water, supply management, bias. The aim to inform more effective water resources planning in the region is repeated here and is the need to highlight the potential of local dryland farming.

7.3 Green and blue virtual water 'trade' in the MENA

This section will explore the structure and evolution of green and blue virtual water 'trade' in the MENA in order to answer the question:

To what extent have green and blue water resources underpinned the MENA virtual water 'trade'?

The answer to this question will reveal the invisible impacts of commodity trade on water resources, both in the MENA region and in the environments of its virtual water trade partners. The extent to which the MENA countries deploy high-opportunity cost blue water for producing agricultural goods for export, as well as the main sources of virtual water 'inflows' to the MENA region from the world's exporting economies will be explored. As previously argued, 'trading' green water is more sustainable than 'trading' blue water for three main reasons. First, green water has a low opportunity cost in relation to blue water, as it can perform only two functions, that is, sustaining agricultural production or natural vegetation and its related ecosystem services and related amenities. Secondly, blue water allocated to irrigation yields the lowest economic value among all alternative uses (industry, services and domestic use). Thirdly, the use of blue water in irrigated agriculture is associated with negative environmental externalities (such as water logging, salinization etc.) and also entails the risk of over-allocation. The environmental cost of using blue water is particularly high when it originates from fossil aquifers.

The chapter will answer the overarching research question and sub-questions presented in Section 6.1.1, and corroborate the related hypotheses by following *five* main steps:

- Assessing the green and blue virtual water ‘embedded’ in trade in agricultural commodities, both in the MENA and globally *(sub-question 1)*;
- Differentiating the volumes of green and blue virtual water ‘embedded’ in the MENA intra-regional and extra-regional trade in agricultural goods, and assessing virtual water ‘flows’ in the different types of traded agricultural products (*sub-question 2*);
- Identifying the MENA virtual water import ‘trade’ partners in green and blue water (*sub-question 3*);
- Analysing the contribution of the different types of agricultural commodities in the MENA ‘import’ and ‘export’ in virtual water (*sub-question 4*);
- Assessing virtual water ‘trade’ in green and blue virtual water at the country level (*sub-question 5*).

The recent studies by Tamea *et al*. (2013) and Carr *et al.* (2013) provide the main datasets deployed for the assessment of green and blue virtual water ‘flows’ at the global level and for the MENA countries. The period considered in this analysis is 1986-2010.

The overarching hypothesis to be corroborated is that *green water* is the main source of water ‘embedded’ in both imports and exports in the MENA region. Blue water will be shown, however, to be a substantial source of virtual water ‘embedded’ in the region’s exports, and the main source of water ‘embedded’ in the exported non-edible agricultural products. It will be argued that virtual water ‘exports’ from the MENA economies have been environmentally determined; whereas virtual water ‘imports’ have been driven mainly by the region’s food-demands.

As shown in Chapter 6, the capacity to meet the increasing need for food of the region's populations has been assisted by a downward trend in food prices, which has made the import of food commodities economically (as well as politically) feasible in the bulk of the MENA countries. This condition was the case until 2003 when there was a slight increase on global food prices (FAO Trade Statistics database). The final outcome of the 2008-2013 global commodities price spikes associated with the oil price spikes have yet to be revealed. Food prices are falling but not yet to their 2008 levels. These changing conditions raise concerns about the sustainability of the virtual water 'solution' for the low-adaptive MENA countries in the future.

7.3.1 Global green and blue virtual water 'flows'

The aim of this section and the following (Section 7.3.2) is to address the first sub-question of this chapter, that is:

How has green and blue virtual water 'trade' in agricultural commodities evolved over the past three decades, both globally and in the MENA region?

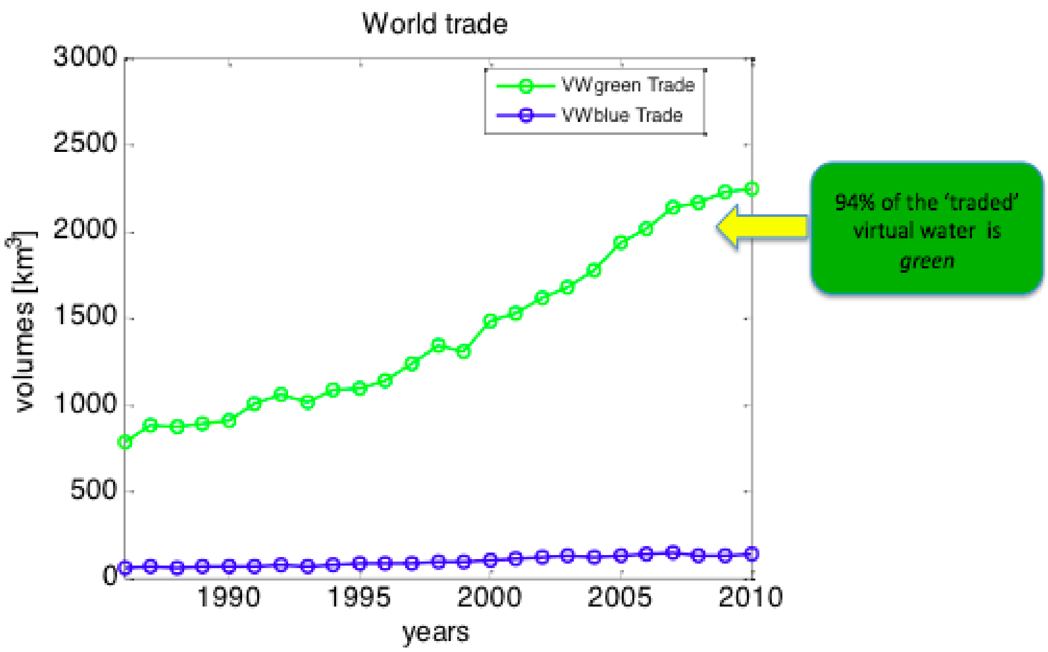
The study hypothesised that green water accounts for the largest share of virtual water 'trade' both in the MENA and globally. In order to answer the identified research question and corroborate the related hypothesis, the virtual water 'exchange' implicit in agricultural commodity trade both globally and in the MENA region, over the past two and a half decades, will be analysed. In the following section, the different types of agricultural commodities associated with the MENA virtual water 'imports' and 'exports' in green and blue water are differentiated.

Figure 7.1 shows the green and blue water 'embedded' in global trade in agricultural commodities over the period 1986-2010.

By an order of magnitude green virtual water 'trade' is higher than blue virtual water 'trade'. As shown in Chapter 6, the volumes of virtual water 'embedded' in trade in agricultural commodities averaged, over this time span, 1,512 km^3 per year. 'Trade' in green virtual water averaged 1,416 km^3 per year, whereas blue virtual water 'flows' averaged about 97 km^3 per year. Green water dominated virtual water 'trade' - accounting for 94% of the global water 'traded' (Figure 7.2). The major world's exporting economies rely on rainfed agriculture for agricultural production (IMWI 2007; Wani *et al.* 2009; Fader *et al.* 2011). Rainfed agriculture contributes almost 60% to the global food basket (Wani *et al.* 2009).

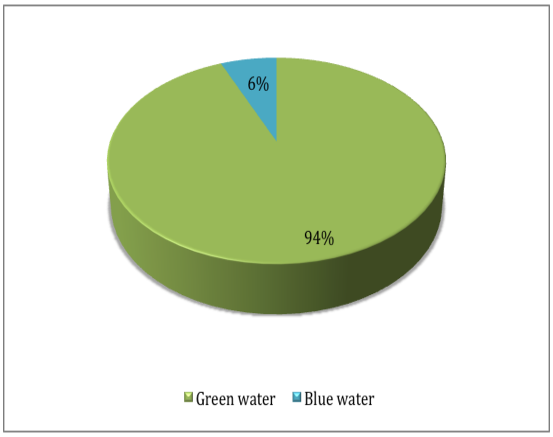
The volumes of 'traded' green water grew much faster than blue virtual water 'trade', which remained relatively constant in volume. As green water represents by far the largest proportion of the water 'traded' at the global level, its increase over the period considered is a reflection of the intensification of international commodity trade (more details on the relationship between the temporal dynamics of global virtual water 'trade' and international commodity trade in the selected decades were provided in Chapter 6). The findings of this section are consistent with other studies distinguishing between the two sources of water 'embedded' in agricultural trade (Liu *et al.* 2009; Aldaya *et al.* 2010a; Hanasaki *et al.* 2010; Fader *et al.* 2011; Konar *et al.* 2012), as well as in agricultural and industrial commodity trade (Hoekstra and Mekonnen 2012). Table 7.1 summarises the findings presented here.

Figure 7.1 Green and blue virtual water 'trade' (1986-2010)



Source: Elaboration based on Tamea et al. 2013 and Carr et al. 2013

Figure 7.2 Green and blue virtual water as a percentage share of the world's average 'traded' virtual water (1986-2010)



Source: Elaboration based on Tamea et al. 2013 and Carr et al. 2013

Table 7.1 Green and blue virtual water 'embedded' in global trade in agricultural products: average, trend and percentage variation (1986-2010)[47]

[47] Average is calculated over the 25 years. Trend and percentage values refer to the comparison of years 1986 and 2010.

	Average (1986-2010)	**Trend**	**Variation**
GW 'trade'	1,416 km^3/year	Positive	+ 187%
BW 'trade'	97 km^3/year	Positive	+144%

Source: Elaboration based on Tamea et al. 2013 and Carr et al. 2013

Note: GW stands for *green water;* BW stands for *blue water*

7.3.2 Green and blue virtual water 'flows' in the MENA

This section investigates the 'flows' of green and blue virtual water 'embedded' in the MENA trade in agricultural commodities over the period 1986-2010[48]. The commodities considered are crops, animal products, lux-foods and non-edible agricultural commodities. The research question addressed in this section is the first sub-question of the chapter (*"How has green and blue virtual water 'trade' in agricultural commodities evolved over the past three decades, both globally and in the MENA region?"*).

Figure 7.3 shows that green water is not only the main source of water 'embedded' in agricultural commodity trade at the global level but also in the MENA, accounting for 87%, on average, of the total virtual water 'traded' by the region's economies over the period considered. Green virtual water 'trade' in the MENA averaged 173 km^3 per year; whereas blue water 'trade' averaged 25 km^3 per year. The MENA virtual water 'trade' accounts for 26% of global *blue* virtual water 'trade' and 12% of global virtual water 'trade' in *green* water.

Green water is the main source of both the MENA 'imports' and 'exports'. Green virtual water is 90% of total water 'imports'; whereas the proportion of green water 'exported' by the region's economies is smaller, standing at 74% of total 'exports'. Almost one third of the MENA production of agricultural products for export relies on blue water resources, that is freshwater abstracted from surface and groundwater bodies. As detailed in Chapter 2, in the MENA countries, blue

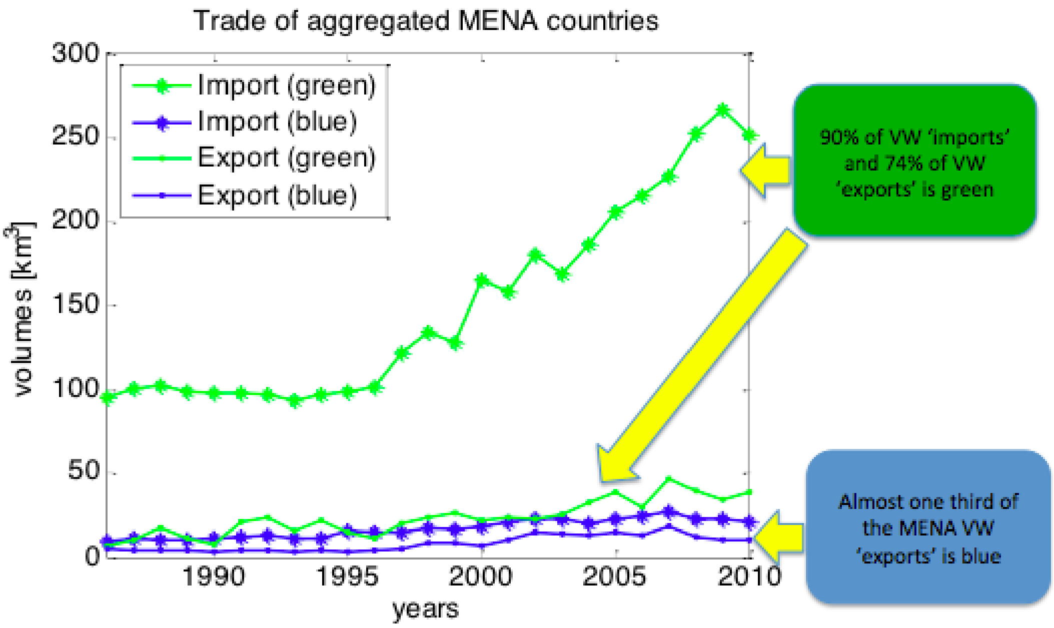
[48] The 'flows' considered here include both intra-regional and extra-regional trade in agricultural commodities.

water resources are in fact overwhelmingly allocated to the agricultural sector, especially in Syria, Iran, Yemen, UAE, Saudi Arabia, Oman, Tunisia, Morocco, Libya, and Egypt, where agricultural water withdrawals exceed 80% of total water use (AQUASTAT 2012).

The use of blue water in agriculture has brought about a number of environmental externalities. These externalities have often been associated with over-allocation. Green water resources cannot be over-allocated and have far fewer negative externalities on natural ecosystems (Aldaya *et al.* 2010a). Blue water use in agriculture also competes with other economic uses that generate much 'more value per drop'[49]. Section 7.3.2.3 will investigate the composition of virtual water 'exports' from the MENA economies and distinguish high-value crops (fruit and vegetables) from low-value crops (cereals). Table 7.2 summarises the main findings presented in this section.

Figure 7.3 Green and blue virtual water 'trade' in the MENA (1986-2010)

[49] It has been highlighted, however, that the use of green water for agricultural production may determine a loss of ecosystem diversity and, as a consequence, a reduction of welfare-supporting ecosystem services resting on them (WWF-Italy 2014).



Source: Elaboration based on Tamea et al. 2013 and Carr et al. 2013

Table 7.2 Green and blue virtual water 'embedded' in the MENA trade in agricultural products: total volumes, average, trend and percentage variation (1986-2010)[50]

	1986 [km^3]	**1998** [km^3]	**2010** [km^3]	**Average** (1986-2010)	**Trend**	**Variation**
GW 'import'	95	134	252	149.7	Positive	+165%
BW 'import'	9	17	21	16.8	Positive	+128%
GW 'export'	6	23	38	23.2	Positive	+494%
BW 'export'	5	9	10	8	Positive	+107%

Source: Elaboration based on Tamea et al. 2013 and Carr et al. 2013

Note: GW stands for *green water;* BW stands for *blue water*

[50] Average is calculated over the 25 years. Trend and percentage values refer to the comparison of years 1986 and 2010.

7.3.2.1 The structure of green and blue virtual water 'trade' in the MENA region: intra-regional and extra-regional virtual water 'flows'

This section investigates the structure of the MENA virtual water 'trade' by showing the extent to which the MENA 'trade' in green and blue water is associated with intra-regional and extra-regional agricultural commodity trade. The aim of this section is to answer the second sub-question of this chapter, that is:

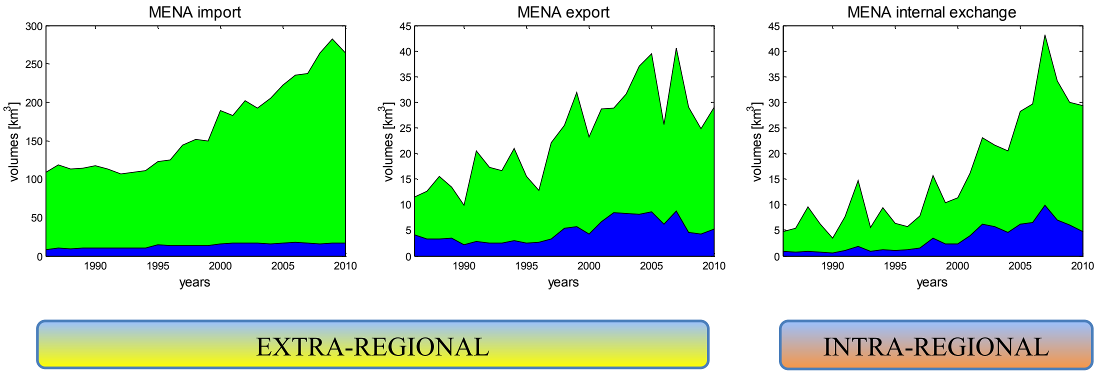
What has been the structure of green and blue virtual water 'trade' in the MENA over the past three decades? That is, to what extent have the MENA countries 'exchanged' green and blue virtual water between themselves and with the rest of the world?

In order to answer these questions, the MENA intra-regional and extra-regional green and blue virtual water 'trade', in the period 1986-2010, will be differentiated. Intra-regional virtual water 'trade', as explained in Chapter 6, include *all* the 'exchanges' of virtual water between the MENA economies (both imports and exports); whereas extra-regional virtual water 'trade' is sub-divided in 'imports' and 'exports'.

Figure 7.4 compares intra-regional and extra-regional green and blue virtual water 'trade'. It is noteworthy that the scale of the MENA 'exports' and intra-regional virtual water 'trade' is far lower than virtual water 'imports'. The metrics for the region confirm those identified by Zeitoun *et al.* (2010) for the Nile Basin economies. Green water is the main source of extra-regional virtual water 'imports' and 'exports', as well as intra-regional 'trade'. On average, this source of water accounted for 91% of the extra-regional virtual water 'imports' and 74% of 'exports'; and 75% of the water 'exchanged' *within* the MENA economies. On average the MENA 'exports' 5 km^3 of blue water per year *outside* the region; whereas, 3 km^3 per year, on average, are 'exchanged' *within* the region.

All the flows considered show positive trends over time. Blue virtual water 'imports' increased twofold, over the 25 years considered; virtual water 'exports' (both extra-regional and intra-regional) grew substantially, although with several fluctuations, in the 2000s but decreased in the last years considered. Table 7.3 summarises these findings.

Figure 7.4 The MENA intra-regional and extra-regional green and blue virtual water 'trade' (1986-2010)



Source: Elaboration based on Tamea et al. 2013 and Carr et al. 2013

Table 7.3 Green and blue virtual water 'embedded' in intra-regional and extra-regional trade in agricultural products: total volumes, average, trend and percentage variation (1986-2010)[51]

		1986 [km³]	**1998** [km³]	**2010** [km³]	**Average** (1986-2010)	**Trend**	**Variation**
Outside the MENA	**GW 'import'**	92	125	232	140	Positive	+152%
	BW 'import'	8	13	16	14	Positive	+92%
	GW 'export'	3	15	18	14	Positive	+447%
	BW 'export'	4	5	5	5	Positive	+31%
Within the MENA	**GW 'trade'**	3	9	20	9	Positive	+546%
	BW 'trade	1	3	5	3	Positive	+487%

Source: Elaboration based on Tamea et al. 2013 and Carr et al. 2013

Note: GW stands for *green water;* BW stands for *blue water*

[51] Average is calculated over the 25 years. Trend and percentage values refer to the comparison of years 1986 and 2010.

7.3.2.2 The MENA virtual water 'trade' partners

The MENA virtual water 'import' trade partners and 'export' destinations have been analysed in Chapter 6. In this section, the different sources of agricultrual water 'embedded' in the commodities exported by the MENA virtual water 'import' trade partners will be distinguished. The purpose is to understand the extent to which the MENA virtual water 'import' trade partners rely on green and blue water resources for producing the commodity they export and to discuss the implications of virtual water 'trade' in these countries. This section addresses the third subsidiary question of the chapter, i.e.:

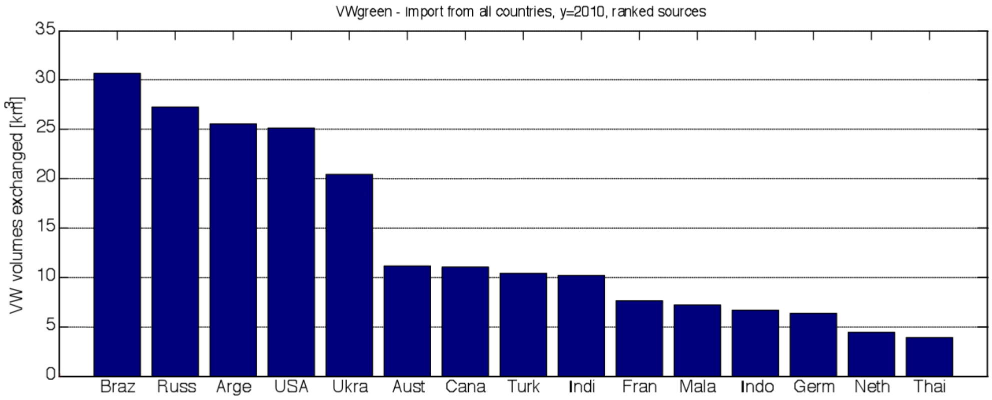
Which have been the main green and blue virtual water import 'trade' partners of the MENA economies?

Two types of virtual water 'import' trade partners are identified here:

- *Green virtual water 'import' trade partners*, i.e. the origins of *green* virtual water 'inflows' to the MENA region;
- *Blue virtual water 'import' trade partners*, i.e. the origins of *blue* virtual water 'inflows' to the MENA region;

Figure 7.5 and 7.6 identify the MENA virtual water 'import' trade partners by the distinguishing the source of agricultural water 'embedded' in agricultural commodity trade in 2010. Total 'imported' volumes by country are shown in the left axis; cumulative percentages of virtual water 'imports' are shown in the right axis.

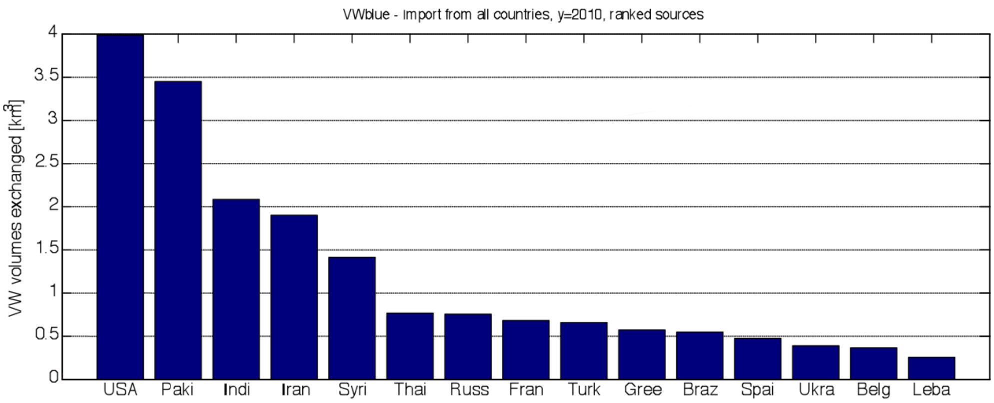
Figure 7.5 The MENA *green* virtual water 'import' trade parters in the year 2010: total volumes



[1] 'Brazil'	[6] 'Australia'	[11] 'Malaysia'
[2] 'Russia'	[7] 'Canada'	[12] 'Indonesia'
[3] 'Argentina'	[8] 'Turkey'	[13] 'Germany'
[4] 'USA'	[9] 'India'	[14] 'Netherlands'
[5] 'Ukraine'	[10] 'France'	[15] 'Thailand'

Source: Author Elaboration based on Tamea et al. 2013 and Carr et al. 2013

Figure 7.6 The MENA *blue* virtual water 'import' trade parters in the year 2010: total volumes (left axis)

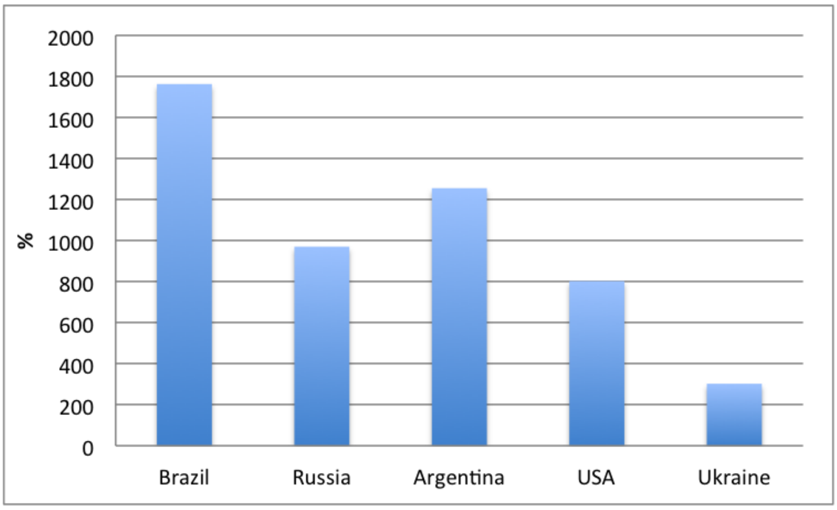


[1] 'USA'	[6] 'Thailand'	[11] 'Brazil'
[2] 'Pakistan'	[7] 'Russia'	[12] 'Spain'
[3] 'India'	[8] 'France'	[13] 'Ukraine'
[4] 'Iran'	[9] 'Turkey'	[14] 'Belgium'
[5] 'Syria'	[10] 'Greece'	[15] 'Lebanon'

Source: Elaboration based on Tamea et al. 2013 and Carr et al. 2013

The scale of green and blue virtual water 'imports' is dramatically different. Virtual water 'imports' of green water reach up to 30 km^3 per year; whereas, blue virtual water 'imports' do not exceed 4 km^3 per year. Brazil, Russia, Argentina, USA and Ukraine have been the main virtual water 'import' trade partners of the MENA (as shown in Chapter 6). They have also been the main *green* virtual water 'import' trade partners of the region. The 'exports' from these countries to the MENA economies accounts for about 50% of the region's total green virtual water 'inflows'. These green water 'exporting' countries are all food-water secure, as local water availabilities far exceed the water needed for food security of local populations[52] (Figure 7.7). Crops are the main agricultural commodities associated with green virtual water 'outflows' from these countries. Brazil is also a major exporter of virtual water 'embedded' in lux-foods and animal products (more details will be provided in Section 7.3.2.3).

Figure 7.7 Food-water scarcity degrees in the main *green* virtual water 'import' trade partners of the MENA region (%)



Source: Elaboration based on Gerten et al. 2011

[52] Food-water security, as shown in Chapter 5, can be calculated as the percentage share between a country's water availability and its water requirements to produce a diet of 3,000 kcal per capita per day, with 80% vegetal and 20% animal-based products. This diet can be considered as a benchmark for hunger alleviation and can thus be taken as a measure of a country's water-for-food security (Rockström *et al.* 2009; Gerten *et al.* 2011).

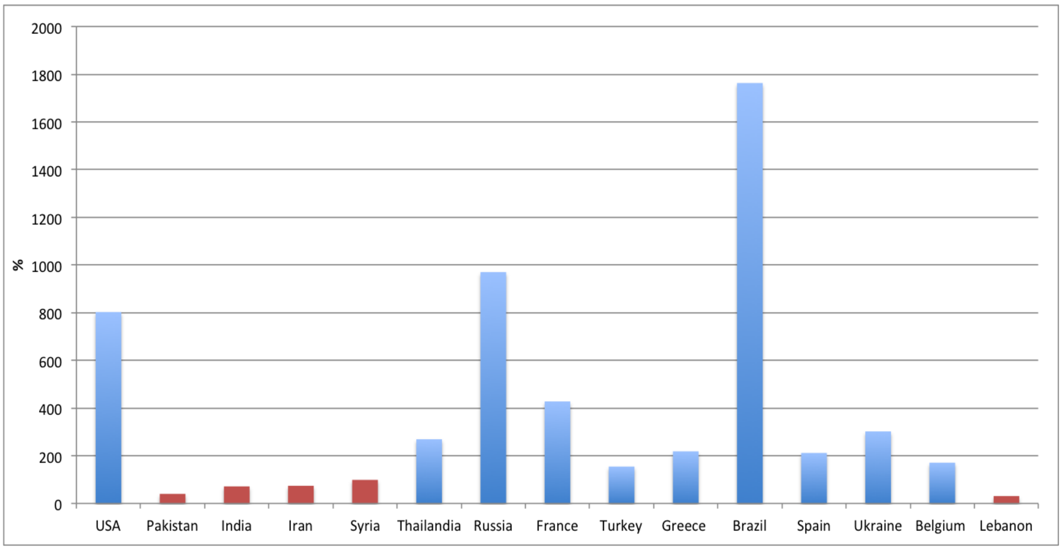
Figure 7.6 ranks the MENA trade partners whose ‘export’ in blue water accounts for 80% of the MENA total blue virtual water ‘imports’. About 50% of the MENA total blue water ‘imports’ originates from four countries, namely, the USA, Pakistan, India and Iran. Blue virtual water ‘exports’ from the USA are mainly associated with non-edible agricultural commodity exports. Interestingly, Turkey is the only country ranked among the MENA *green* virtual water ‘import’ trade partners (Figure 7.5); whereas, a number of MENA countries – namely, Iran, Syria, Turkey and Lebanon – are *blue* virtual water ‘exporters’.

The potential impacts of virtual water ‘trade’ in the blue-water ‘exporting’ economies, which include both MENA and non-MENA countries, can be evaluated by looking at the degree of food-water scarcity of these countries (Figure 7.8). Levels of water scarcity below 100%, indicating a country’s food-water availabilities *below* water requirements for food security, are marked in red. Turkey, as shown in Chapter 5, is the only MENA country that can be considered as food-water secure. Food-water scarce countries instead include Lebanon and Pakistan, as well as India, Iran and Syria, although to a lower extent. Syria and Iran are relatively food-water secure, with scarcity degrees between 75% and 100%.

These countries also suffer from *blue water scarcity of local river basins.* In all these countries environmnetal flow requirements are not met, although to different extents (Hoekstra and Mekonnen 2011)[53]. Table 7.4 illustrates the degree of blue water scarcity of the main blue water ‘exporting’ countries to the MENA region.

[53] These data refer to *annual average monthly blue water scarcity* in the world’s major river basins, calculated by equal weighting the twelve monthly blue water scarcity values per basin over the period 1996-2005 (Hoekstra and Mekonnen 2011).

Figure 7.8 Food-water scarcity degrees in the main *blue* virtual water 'import' trade partners of the MENA region (%)



Source: Elaboration based on Gerten et al. 2011

Table 7.4 Blue water scarcity of local river basins (1996-2005) in the MENA blue virtual water 'import' trade partners

Degree of blue water scarcity of local river basins	Country
Low and/or moderate	Russia, France, Ukraine, Turkey, Brazil
From low/moderate to severe	USA, Spain
Significant	Syria, Iran
Severe	Pakistan, India, Lebanon

Source: Elaboration based on Hoekstra and Mekonnen 2011

The following sections (Section 7.3.2.3 and 7.3.2.4) will identify the main green and blue virtual water 'trade' partners of the MENA region by distinguishing four types of traded agricultural goods (namely, crops, lux-foods, animal products and non-edible commodities).

7.3.2.3 The MENA virtual water ‘imports’ of green and blue water by category of traded agricultural commodity

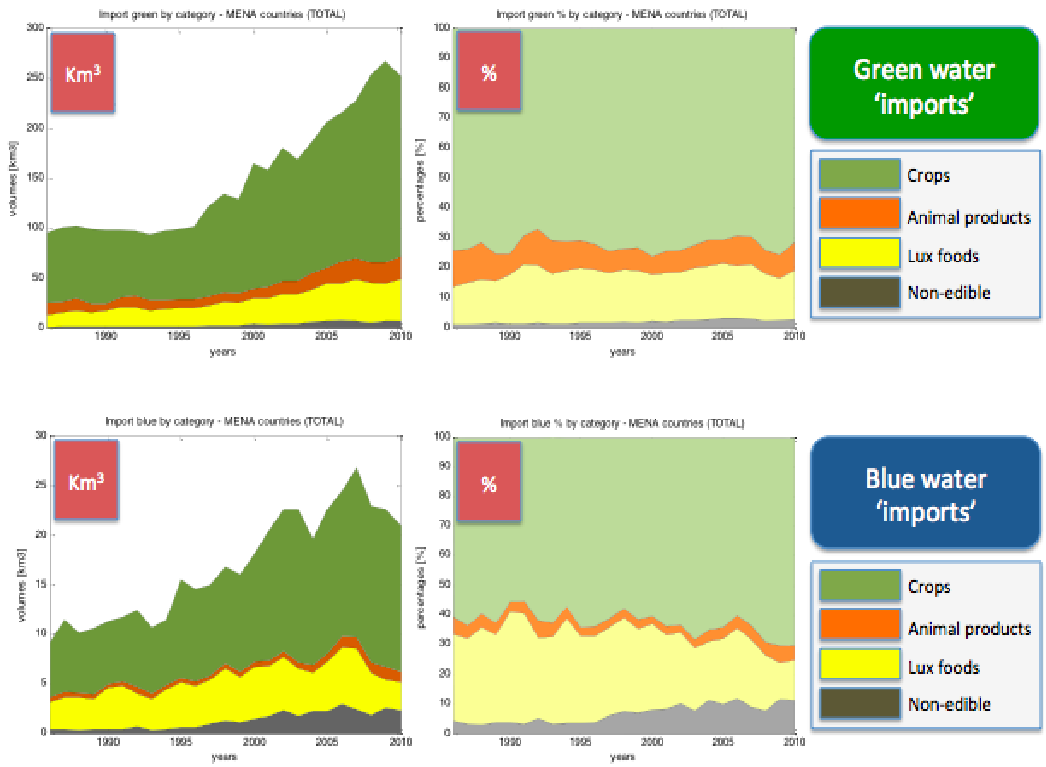
The aim of this section is to investigate the composition of virtual water ‘imports’ by differentiating the virtual water ‘embedded’ in the different types of agricultural commodities imported by the MENA region over the period 1986-2010.

Figure 7.9 differentiates the green and blue virtual water ‘embodied’ in the MENA imports of food (crops, animal products, lux-foods) and non-edible agricultural products. The four quadrants show:

- The green virtual water ‘imports’ over the period 1986-2010 by category of traded commodities (*top left*); and the relative contribution of each category of agricultural product to total green virtual water ‘imports’ (*top right*), measured as the annual percentage share of each group of commodity to the MENA total ‘import’ of green water;
- The blue virtual water ‘imports’ over the period 1986-2010 by category of traded commodities (*bottom left*); and the relative contribution of each category of agricultural product to total blue virtual water ‘imports’ (*bottom right*), measured as the annual percentage share of each group of commodity to the MENA total ‘import’ of blue water.

Blue and green virtual water ‘imports’ differ significantly in volume. Green water ‘imports’ average 150 km^3 per year; blue water ‘imports’ instead 17 km^3 per year. The MENA ‘import’ of green water is mainly associated with crops (108 km^3 per year), followed by lux-foods (25 km^3 per year), animal products (13 km^3 per year) and non-edible agricultural commodities (3 km^3 per year). The ‘import’ of green water associated with all the types of agricultural products increased substantially over the period considered; whereas the relative contribution of each category to total imports did not change much, fluctuating around intermediate values. The ‘import’ of blue water is mainly associated with crops (11 km^3 per year on average), followed by lux-foods (4 km^3 per year), non-edibles (1 km^3 per year) and animal products (0.6 km^3 per year). The largest increase in blue virtual water ‘imports’ is associated with non-edible agricultural commodity trade, which show a seven-fold increase over the period considered.

Figure 7.9 Green and blue virtual water ‘imports’ in the MENA by category of traded agricultural commodity: total volumes (left) and percentage shares (right) (1986-2010)



Source: Elaboration based on Tamea et al. 2013 and Carr et al. 2013

Over the whole period considered, food products have accounted for at least 90% of both green and blue virtual water ‘imports’. Crops (including cereals, fruit and vegetables) show the largest shares in both green and blue virtual water ‘flows’ (respectively, about 70% and 60% of total ‘imports’ by source of water) (Figure 7.9). The contribution of the different agricultural products to total average virtual water ‘imports’ in green and blue water is shown in Table 7.5. The largest share is represented by crop imports in both green and blue virtual water ‘imports’. Table 7.6 shows the percentage share of green and blue water in total virtual water ‘imports’ by type of traded commodity. The green water share is higher in crops and animal products, compared with lux-foods and, in particular, non-edible commodities.

Table 7.5 The MENA virtual water 'imports' by source of water: volumes by type of traded agricultural commodities and relative percentage share (average 1986-2010)[54]

	Average BVW 'imports' [km^3/year]	**Share in total BW 'imports'**	**Average GVW 'imports'** [km^3/year]	**Share in total GW 'imports'**
Crops	10.7	63%	108.5	72%
Animal products	0.7	4%	13	9%
Lux-foods	4.2	25%	24.9	17%
Non-edible	1.3	8%	3.3	2%
TOT	17	100%	150	100%

Source: Elaboration based on Tamea et al. 2013 and Carr et al. 2013

Table 7.6 Green and blue virtual water percentage share in total virtual water 'imports' by type of traded commodity (average 1986-2010)[55]

	Total VW 'imports' [km^3/year]	**BW share**	**GW share**
Crops	119	9%	91%
Animal based	14	5%	95%
Lux-foods	29	15%	85%
Non-edible	5	28%	72%

Source: Elaboration based on Tamea et al. 2013 and Carr et al. 2013

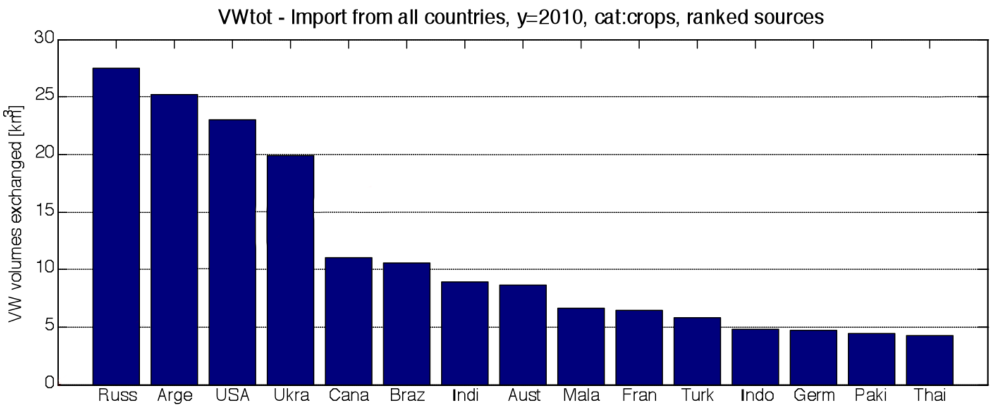
On average, 91% of the MENA total virtual water 'imports' in crops derives from green water (Table 7.5). This is to say that the main virtual water 'import' trade partners in crops of the MENA produce mainly under rainfed conditions. In 2010, virtual water 'exports' from Russia, Argentina, the USA and Ukraine accounted for 60% of total virtual water 'imports' implicit in the MENA import of crops

[54] Average is calculated over the 25 years. Percentage values refer to the average total virtual water 'exports' over the period 1986-2010.

[55] Average is calculated over the 25 years. Percentage values refer to the average total virtual water 'imports' over the period 1986-2010.

(Figure 7.10). This finding is consistent with previous assessments addressing the predominant role of green water in crop production and agricultural commodity trade (among others, Liu *et al. 2009;* Aldaya *et al.* 2010a; Siebert and Doll 2010; Konar *et al.* 2012).

Figure 7.10 The MENA virtual water 'import' trade partners in *crops*: volumes (2010)



[1]	'Russia'	[6]	'Brazil'	[11]	'Turkey'
[2]	'Argentina'	[7]	'India'	[12]	'Indonesia'
[3]	'USA'	[8]	'Australia'	[13]	'Germany'
[4]	'Ukraine'	[9]	'Malaysia'	[14]	'Pakistan'
[5]	'Canada'	[10]	'France'	[15]	'Thailand'

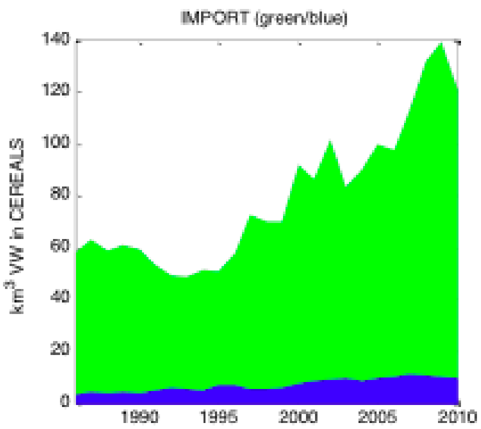
Source: Elaboration based on Tamea et al. 2013 and Carr et al. 2013

Cereals account for 67% of the region's average total import of crops (which also includes vegetables and fruits) over the period considered[56]. The virtual water 'embedded' in the MENA imports of cereals is predominantly *green* (91%) (Figure 7.11). In all the MENA 'import' trade partners in crops (identified in Figure 7.10), cereal harvesting is in fact predominantly rainfed (Rosegrant *et al.* 2002; Bruisma 2009).

Figure 7.11 The MENA green and blue virtual water 'imports' in *cereals*

[56] Cereals include maize, rice, wheat, barley, sorghum, millet, oats, triticale, rye, buckwheat, fonio, quinoa in all forms, primary and derived-flours.

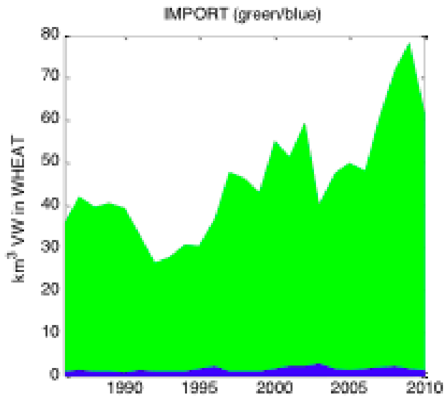
(1986-2010)



Source: Elaboration based on Tamea et al. 2013 and Carr et al. 2013

The import of wheat by the MENA countries account for 58% of the total 'import' of virtual water in cereals and 38% in crops. As shown in Figure 7.12, it is mainly green water-sourced (97%). This is consistent with global trade in wheat where 80% of production is rainfed (Liu *et al.* 2009). In most of the virtual water 'import' trade partners of the MENA region, some of which are also the largest wheat producers worldwide, wheat is harvested mainly in rainfed systems. Apart from Germany and France, which produce under a high-input rainfed farming system, in the rest of the MENA partners, the gap between actual and attainable yields in relation to local agro-economic potential is significant. The USA, Ukraine and Russia show the highest potential for cereal yield growth (Bruisma 2009; Lioubimtseva 2010).

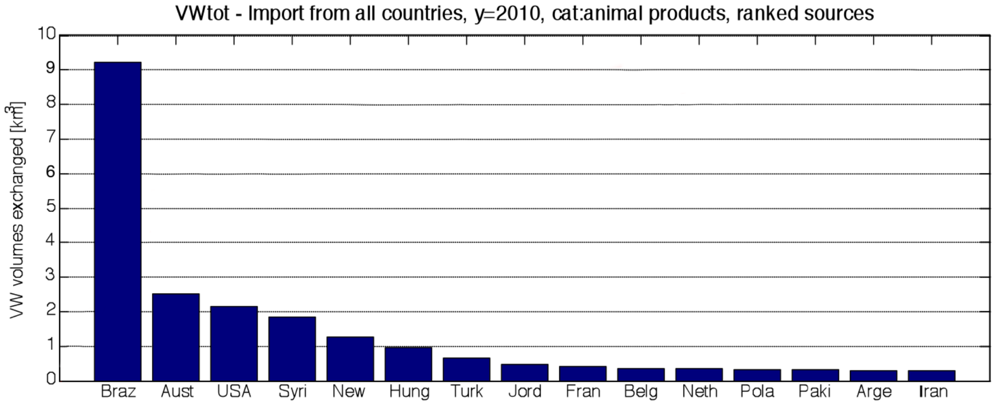
Figure 7.12 The MENA green and blue virtual water 'imports' in *wheat* (1986-2010)



Source: Elaboration based on Tamea et al. 2013 and Carr et al. 2013

The import of animal products (live animals, meat and diary) is also mainly green-water sourced. As shown in Figure 7.13, Brazil is the largest virtual water 'trade' partner in animal-based products of the MENA. In 2010, the 'exports' from Brazil accounted for 40% of the MENA total virtual water 'imports' in animal products, and is mainly associated with bovine meat. Brazil is the first beef and veal exporter in the world (USDA 2013). Both agricultural production and grazing in the country are predominantly rainfed (Rosegrant *et al.* 2002). Important virtual water 'import' trade partners in animal products are also Australia, USA, Syria and New Zealand. Australia, USA and New Zealand are among the five largest exporters of bovine meat worldwide (USDA 2013). The MENA imports from Australia are mainly in sheep meat, and live sheep and cattle (FAOSTAT 2013). Over the past decade, Australian bovine imports to the MENA region have almost quadrupled, with the UAE, Saudi Arabia and Jordan being Australia's top three largest markets of red meat (Larkin 2013). Syria, the fourth virtual water 'import' trade partner in animal products of the MENA export mainly live sheep and eggs within the region (FAOSTAT 2013).

Figure 7.13 The MENA virtual water 'import' trade partners in *animal products*: volumes (2010)



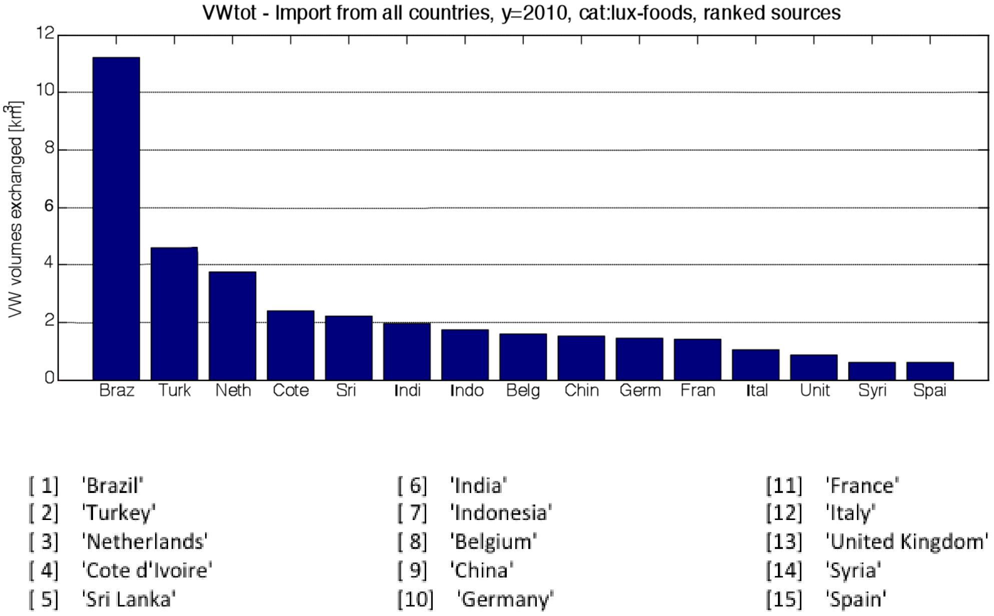
[1]	'Brazil'	[6]	'Hungary'	[11]	'Netherlands'
[2]	'Australia'	[7]	'Turkey'	[12]	'Poland'
[3]	'USA'	[8]	'Jordan'	[13]	'Pakistan'
[4]	'Syria'	[9]	'France'	[14]	'Argentina'
[5]	'New Zealand'	[10]	'Belgium'	[15]	'Iran'

Source: Elaboration based on Tamea et al. 2013 and Carr et al. 2013

The blue virtual water component of the MENA imports of lux-foods and non-edible commodities is instead higher compared with crops and animal products. Blue water 'imports' account for 15% of total imports in lux-foods and 28% in non-edible commodities, as shown in Table 7.3. The largest virtual water 'import' trade partner in lux-foods is Brazil (almost 12 km^3 in the year 2010), followed by Turkey and the Netherlands (<4.5 km^3 each). The virtual water 'embedded' in these countries' exports of lux foods accounts for almost 50% of the MENA total 'import' of virtual water in lux-foods (Figure 7.14). The largest virtual water 'outflows' are 'embodied' in the exports of sugar and coffee from Brazil, and chocolate from Turkey and Netherlands (FAOSTAT 2013).

Figure 7.14 The MENA virtual water 'import' trade partners in *lux-foods*:

volumes (2010)



Source: Elaboration based on Tamea et al. 2013 and Carr et al. 2013

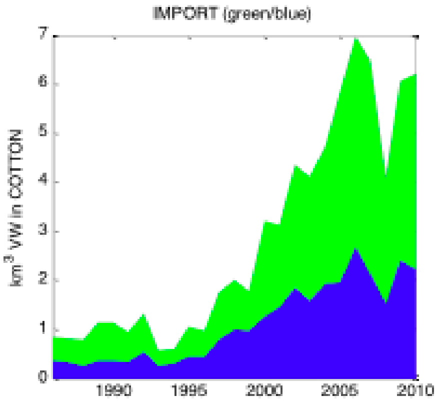
As regards virtual water 'entering' the MENA (both green and blue) through the import of non-edible commodities, it is noteworthy that it is mainly associated with the import of *cotton*[57], which accounts, on average, for 62% of total virtual water 'imports' in non-edible commodities. Cotton is also the main non-edible commodity associated with virtual water 'exports' from the MENA (mainly from Turkey and Egypt), as it will be shown in the following section.

The blue water component is 39% of total average virtual water 'imports' in cotton over the period considered (Figure 7.15). This finding is consistent with other studies reporting that, at the global level, the average blue water proportion of cotton stands at almost 50% of total (green and blue) water use in its production, as opposed to other types of crops (excluding rice), which rely primarily or almost exclusively on green water (Liu *et al.* 2009). Cotton has also one of the highest average water footprints of all agricultural crops. On a global average, the green-blue water footprint of cotton is 3,589 m^3/ton (Mekonnen and Hoekstra 2013).

Figure 7.15 The MENA green and blue virtual water 'imports' in *cotton*

[57] These data refer to lint and carded cotton.

(1986-2010)



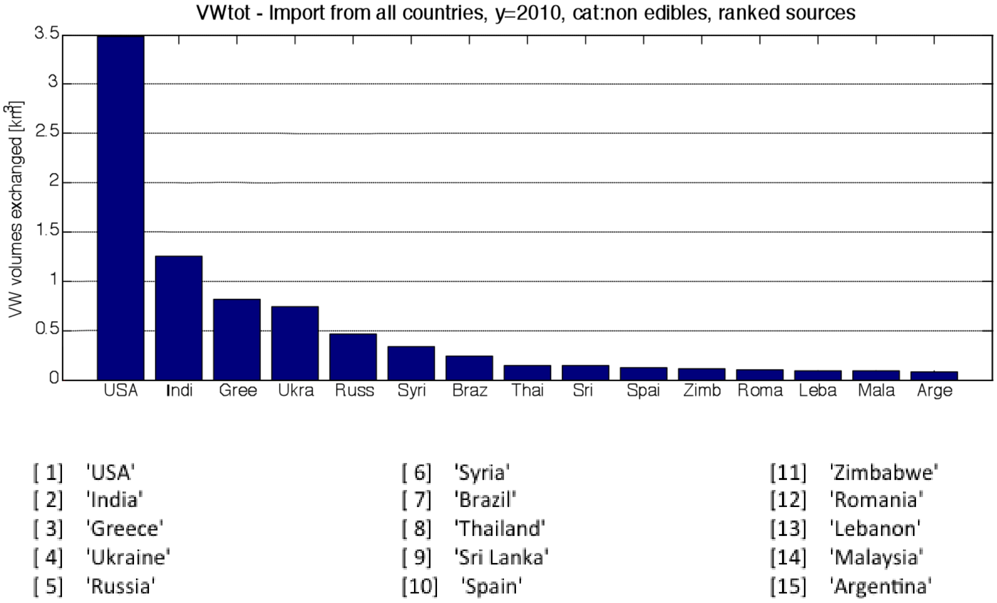
Source: Elaboration based on Tamea et al. 2013 and Carr et al. 2013

Almost half of cotton production worldwide is not for domestic consumption but for export (Chapagain 2008). Irrigated cotton accounts for 73% of global cotton production and is mainly located in dry areas, such as Egypt, Uzbekistan and Pakistan (South *et al.* 1999). The destruction of the Aral Sea ecosystem (between Kazakhstan and Uzbekistan), which has reduced by 60% its area and by 80% its volume in the period 1960-2000 due to the diversion of natural inflows from the Amu Dar'ya and Syr Dar'ya rivers, is probably the most widely known environmental damage caused by irrigation (Pereira *et al.* 2002; Chapagain and Hoekstra 2005). The demand for cotton from the EU is indirectly responsible for about 20% of the shrinking of the Aral Sea (Chapagain 2008).

In Egypt, the production of cotton relies only on blue water resources, as the country virtually has no green water (as shown in Chapter 5). Considerable proportions of irrigated systems in cotton production are also found in parts of (Northern) India and China (South *et al.* 1999). China and India are, respectively, the first and second biggest cotton producers worldwide, followed by the USA (USDA 2013). About 40% of the MENA 'import' of virtual water in non-edible products originates from the USA, followed by India, Greece and Ukraine. These four countries together made up, in the year 2010, almost 70% of total virtual water 'imports' in lux-foods (Figure 7.16).

Figure 7.16 The MENA virtual water 'import' trade partners in *non-edible*

***commodities*: volumes (2010)**



Source: Elaboration based on Tamea et al. 2013 and Carr et al. 2013

7.3.2.4 The MENA virtual water 'exports' of green and blue water by category of traded agricultural commodity

The aim of this section is to investigate the composition of virtual water 'exports' by differentiating the virtual water 'embedded' in the different types of agricultural commodities imported by the MENA region. The section addressed the fourth sub-question of this chapter, that is:

To what extent have the MENA 'exported' virtual water in the different types of agricultural commodities? Which have been the main "channels" of virtual water 'outflows' from the region's economies?

Figure 7.17 differentiates the green and blue virtual water 'embedded' in the MENA export of crops, animal products, lux-foods and non-edible agricultural commodities, over the period 1986-2010.

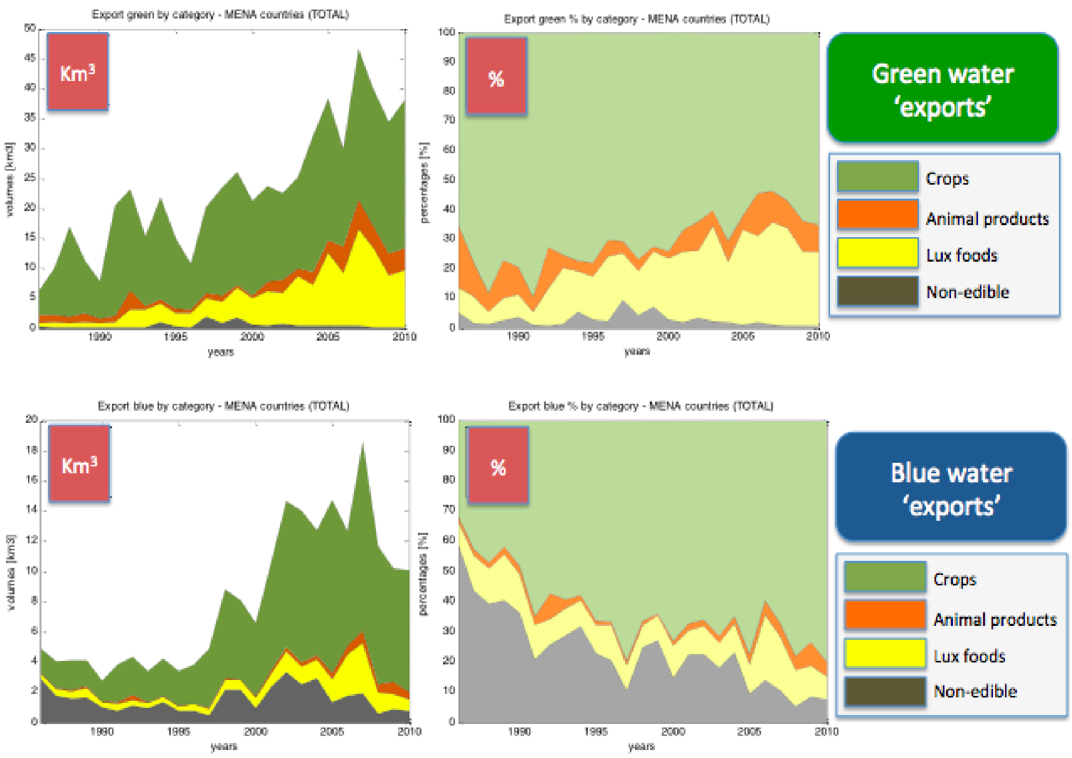
Blue and green virtual water 'exports' differ in scale to a considerable extent. As shown in Section 7.3.2, virtual water 'exports' in green water average 23 km^3 per year, accounting for 74% of the MENA total 'exports' in agricultural products.

Blue water 'exports' are, on average, 8 km^3 per year and accounts for 26% of total 'exports' in virtual water from the MENA economies. This proportion is far higher than the blue virtual water share in the MENA 'imports' (10%), revealing that the economies rely relatively more on surface and groundwater resources than their virtual water 'import' trade partners.

The 'export' of green water averages, over the period considered, 16 km^3 per year for crops, 5 km^3 per year for lux-foods, 2 km^3 per year for animal products and 0.5 km^3 per year in non-edible agricultural products. Being rainfed agricultural systems determined by rainfall, any fluctuations observed in green virtual water 'exports' can be explained by the variability of precipitations in the MENA. Section 7.4 will identify the main green virtual water 'exporters' in the region. The green virtual water 'flows' associated with food products show an increasing trend over the period considered. The largest increase is observed in the volumes of green virtual water 'embedded' in the export of lux-foods and crops. Green water 'exports' associated with non-edible products drop instead by almost 15%, as a result of the decrease in virtual water 'exports' in these types of commodities over the period considered (see Chapter 6, Section 6.4.3). The relative contribution of lux-foods and animal products to total green virtual water 'imports' varies quite considerably. It increases from 9 in 1986 to 25% in 2010 of total 'exports' for lux-foods, and it decreases from 21% in 1986 to 9% in 2010 for animal products.

The 'export' of blue water over the period considered is, on average, 5 km^3 per year for crops, 2 km^3 per year for non-edible commodities, and 1 km^3 per year for lux-foods. The flows associated with the export of animal products are negligible (0.2 km^3 per year). Section 7.4 will identify the main blue virtual water 'exporters' in the MENA. The percentage share of the different types of commodities in total blue virtual water 'trade' varies quite markedly in the case of crops (+152%), animal-based (+184%) and non-edible commodities (-87%).

Figure 7.17 Green and blue virtual water 'exports' by category of agricultural product: total volumes (left) and percentage shares (right) (1986-2010)



Source: Elaboration based on Tamea et al. 2013 and Carr et al. 2013

The MENA virtual water 'export' is mainly associated with trade in food commodities, which accounts for 98% and 80% of the region's total 'exports' in green and blue water, respectively (Table 7.7). Virtual water 'outflows' from the MENA are mainly determined by trade in *crops*, both in the case of green and blue water 'exports'. The proportion of lux-foods is 22% in total green virtual water 'exports' and 11% in blue water 'exports'. Non-edible commodities account for 20% of total average *blue* virtual 'exports' from the MENA, whereas their role in green virtual water 'flows' from the MENA economies is negligible (2%).

The MENA virtual water 'exports' have a significant regional dimension. Iraq is the main virtual water 'export' destination in all the considered food commodities. Italy and the UAE are also important 'export' destinations of virtual water embedded in crops, as well as Algeria in lux-foods. Non-edible agricultural products' virtual water 'exports' are instead mainly towards Turkey, Egypt, Italy and China. A differentiation of virtual water 'export' destination by category of traded agricultural commodity is provided in the Appendix C.

Table 7.7 The MENA virtual water 'exports' by source of water: volumes by type of traded agricultural commodities and relative percentage share (average 1986-2010)[58]

	GW 'exports' [km^3/year]	Share in total GW 'exports'	BW 'exports' [km^3/year]	Share in total BW 'exports'
Crops	15.8	68%	5.3	66%
Animal-based	1.8	8%	0.2	3%
Lux-foods	5.1	22%	0.8	11%
Non-edible	0.6	2%	1.5	20%
TOT	23	100%	8	100%

Source: Elaboration based on Tamea et al. 2013 and Carr et al. 2013

The proportion of green water 'embedded' in food products with respect to non-food products varies quite considerably (Table 7.8). Green water is the main source of water 'embedded' in the MENA exports of crops (75%), animal products (87%), and lux-foods (85%). Non-edible agricultural commodities instead are mainly blue water sourced (74%). The production of these commodities (mainly cotton as in the case of virtual water 'imports') is thus mainly irrigated in the major exporting MENA countries. The main cotton producers in the region are Egypt, which produces *only* in irrigated agricultural systems; as well as Turkey and Tunisia.

Table 7.8 Green and blue virtual water 'exports' in the MENA: total exports by category of agricultural commodity and relative percentage shares in total virtual water 'exports' (average 1986-2010)[59]

[58] Average is calculated over the 25 years. Percentage values refer to the average total virtual water 'exports' over the period 1986-2010.

[59] Average is calculated over the 25 years. Percentage values refer to the average total virtual water 'exports' over the period 1986-2010.

	Total GWBW 'exports' [km³/year]	**BW share**	**GW share**
Crops	21	25%	75%
Animal-based	2	13%	87%
Lux-foods	6	15%	85%
Non-edible	2	74%	26%

Source: Elaboration based on Tamea et al. 2013 and Carr et al. 2013

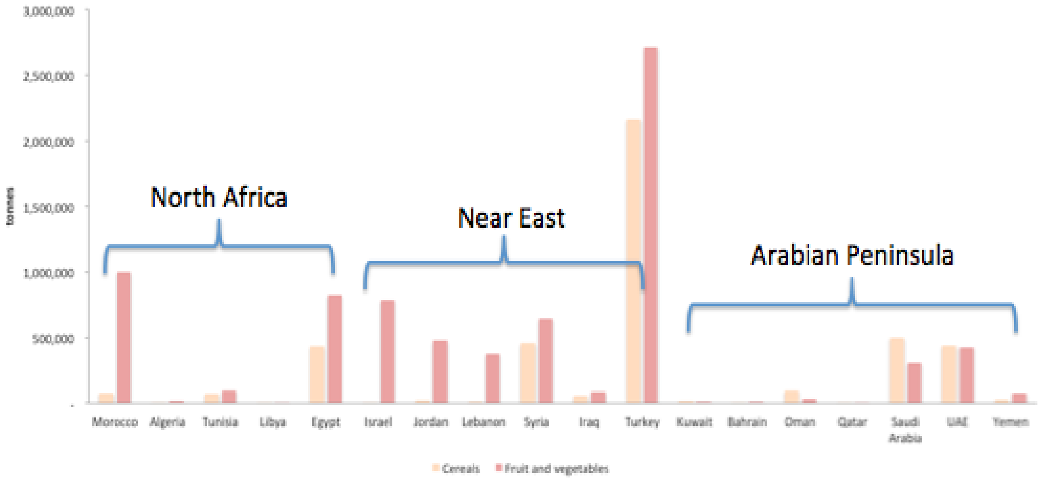
The previous section has shown that cereals account for over 65% of the MENA total average virtual water 'imports' in crops (which also include also fruits and vegetables). The relative importance of cereals in the MENA virtual water 'export' in crops is instead lower (32% of total average virtual water 'exports'). This is to say that about 70% of the MENA virtual water 'outflows' is associated with the export of fruit and vegetables.

The largest exporter of cereals in the region in the study period was Turkey, followed by Saudi Arabia, UAE, and Egypt. Fruit and vegetables are exported by Turkey (1st exporter in the region); followed by Morocco and Egypt in North Africa; and Israel, Syria and Jordan in the Middle East. The export of fruits and vegetables is, in terms of quantity, higher than the export of cereals in all the MENA economies but the Gulf Cooperation Countries (excluding Bahrain). The largest GCC exporters of cereals are Saudi Arabia and the UAE, whereas in Oman, Kuwait and Qatar crop export is negligible (Figures 7.18 and 7.19).

In value terms, cereals account for 12% of the MENA average total export values of crops. The export value of cereals is, in percentage terms, between 40 and 50% of total crop exports in the UAE, Qatar and Oman. In the rest of the MENA countries, it is less than less than 30% of total export values (Figure 7.20). The cereals exported by the MENA economies are mainly green-water sourced (78% on average) (Figure 7.21). About 65% of the MENA virtual water 'exports' in cereals is 'embedded' in *wheat*, 88% of which is, on average, green-water sourced (Figure 7.22).

Section 7.4 will differentiate the source of water 'embedded' in the export of agricultural products of each MENA country.

Figure 7.18 Export of cereals, and fruit and vegetables in the MENA economies: export quantities (average 1986-2010)[60]



Source: Elaboration based on FAOSTAT 2013

Figure 7.19 Export of cereals, and fruit and vegetables in the MENA economies: percentage share of quantity exported (average 1986-2010)[61]

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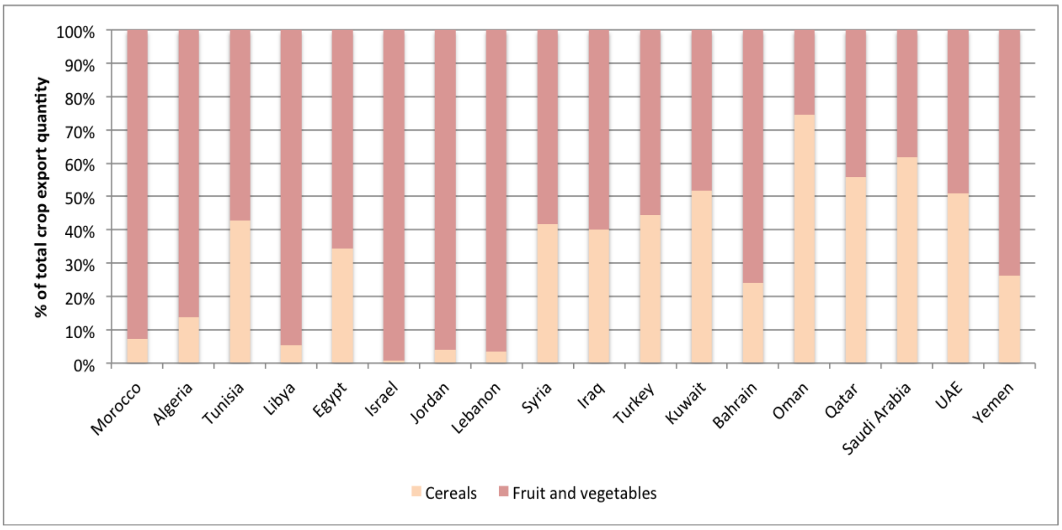
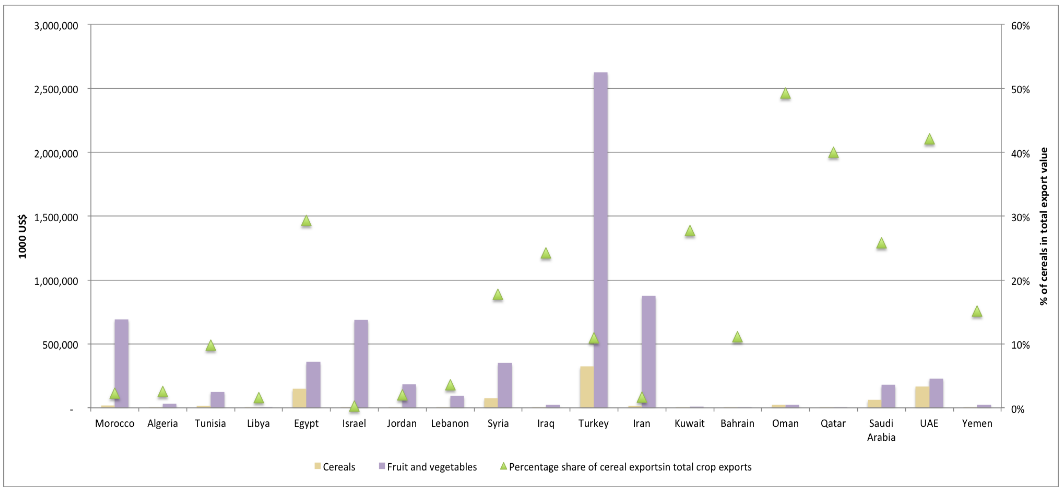
[60] Iran and the Occupied Palestinian Territories are not included due to data limitations.

[61] Iran and the Occupied Palestinian Territories are not included due to data limitations.



Source: Elaboration based on FAOSTAT 2013

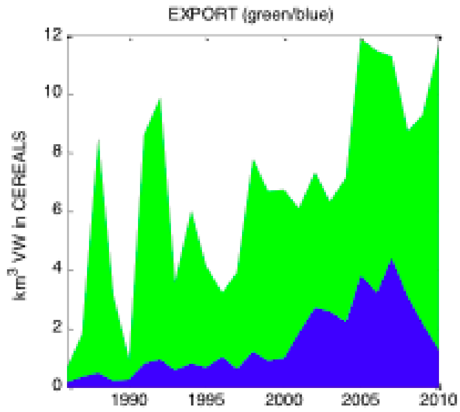
Figure 7.20 Export of cereals, and fruit and vegetables in the MENA economies: export value (average 1986-2010)[62]



Source: Elaboration based on FAOSTAT 2013

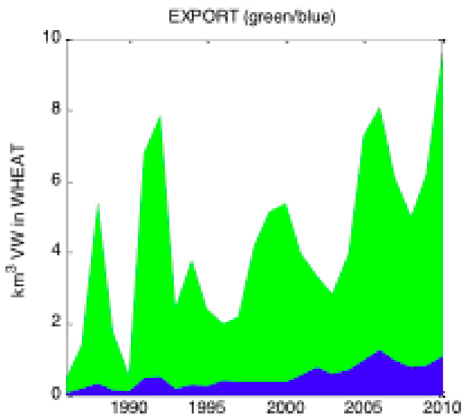
Figure 7.21 The MENA green and blue virtual water 'export' in *cereals* (1986-2010)

[62] The Occupied Palestinian Territories are not included due to data limitations.



Source: Elaboration based on Tamea et al. 2013 and Carr et al. 2013

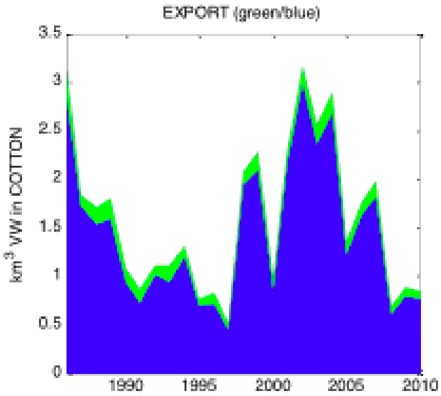
Figure 7.22 The MENA green and blue virtual water 'export' in *wheat* (1986-2010)



Source: Elaboration based on Tamea et al. 2013 and Carr et al. 2013

The largest share of virtual water associated with non-edible commodity exports from the MENA is 'embedded' in *cotton* (75%). In the main exporting countries in the MENA (namely, Turkey, Egypt and Tunisia), cotton crop is mainly irrigated, with a proportion of blue water standing at over 90% (Figure 7.23). Turkey is the largest producer in the region and the 8th exporter at the global level (USDA 2013; UNSD 2014).

Figure 7.23 The MENA green and blue virtual water 'export' in *cotton* (1986-2010)



Source: Elaboration based on Tamea et al. 2013 and Carr et al. 2013

Table 7.9 and 7.10 summarise the findings of Section 7.3.2.3 and 7.3.2.4. The next section will address the extent to which the virtual water 'exchanged' between the MENA countries and with the rest of the world originates from soil water or surface and groundwater resources.

Table 7.9 Green and blue virtual water 'embedded' in the MENA 'imports' and 'exports' by category of agricultural products: total volumes, average and percentage variation (1986-2010)[63]

IMPORTS										
	Green water					Blue water				
	1986 [km3]	1998 [km3]	2010 [km3]	Average [1986-2010]	Variation [%]	1986 [km3]	1998 [km3]	2010 [km3]	Average [1986-2010]	Variation [%]
Crops	70.42	98.5	180.14	108.48	156	5.58	9.74	14.71	10.65	164
Animal-based	11.79	9.17	23.28	12.98	97	0.53	0.51	1.05	0.66	97
Lux-foods	11.94	23.64	41.56	24.92	248	2.69	5.33	2.77	4.23	3
Non-edible	0.87	2.58	6.95	3.29	698	0.38	1.24	2.37	1.27	527
EXPORTS										
	Green water					Blue water				
	1986 [km3]	1998 [km3]	2010 [km3]	Average [1986-2010]	Variation [%]	1986 [km3]	1998 [km3]	2010 [km3]	Average [1986-2010]	Variation [%]
Crops	4.19	17.97	24.82	15.76	492.3	1.55	5.85	8.07	5.33	422
Animal-based	1.35	0.96	3.53	1.81	161.2	0.08	0.12	0.49	0.26	488
Lux-foods	0.56	3.52	9.5	5.12	1603.1	0.38	0.64	0.76	0.89	101
Non-edible	0.32	0.99	0.28	0.55	-12.5	2.87	2.21	0.78	1.58	-73

Source: Elaboration based on Tamea et al. 2013 and Carr et al. 2013

[63] Average is calculated over the 25 years. Percentage values refer to the comparison of years 1986 and 2010.

Table 7.10 Export of cereals, and fruit and vegetables in the MENA economies: import and export quantity and value (average 1986-2010)

	EXPORT QUANTITIES (1986-2010)			**EXPORT VALUE (1986-2010)**		
	Cereals [tonnes]	**Fruit & vegetables** [tonnes]	**Cereals in total exports** [%]	**Cereals** [1000 US$]	**Fruit & vegetables** [1000 US$]	**Cereals in total exports** [%]
Morocco	78,046	1,001,431	7%	16,443	692,011	2%
Algeria	2,644	16,647	14%	848	31,986	3%
Tunisia	73,708	98,737	43%	13,678	125,185	10%
Libya	417	7,308	5%	99	6,188	2%
Egypt	432,144	826,076	34%	148,898	358,076	29%
Israel	5,407	785,781	1%	2,166	688,549	0%
Jordan	19,925	476,225	4%	3,855	182,600	2%
Lebanon	13,846	373,877	4%	3,493	93,724	4%
Syria	457,918	642,630	42%	75,512	349,959	18%
Iraq	58,212	86,717	40%	6,961	21,702	24%
Iran	-	-	-	323,800	2,624,741	11%
Turkey	2,163,414	2,713,429	44%	14,885	874,239	2%
Kuwait	14,942	13,911	52%	4,520	11,769	28%
Bahrain	3,578	11,220	24%	587	4,676	11%
Oman	96,145	32,849	75%	23,086	23,795	49%
Qatar	1,605	1,265	56%	639	958	40%
Saudi Arabia	499,242	308,961	62%	62,235	178,786	26%
UAE	439,978	425,622	51%	167,873	230,434	42%
Yemen	26,415	74,521	26%	4,169	23,274	15%
MENA	**4,387,586**	**7,897,207**	**36%**	**873,746**	**6,522,651**	**12%**

Source: Elaboration based on FAOSTAT 2013

7.4 Green and blue virtual water 'trade' in the MENA countries

The aim of this section is to answer the fifth sub-question of this chapter, that is:

To what extent have the MENA countries been 'net importers' of green and blue virtual water?

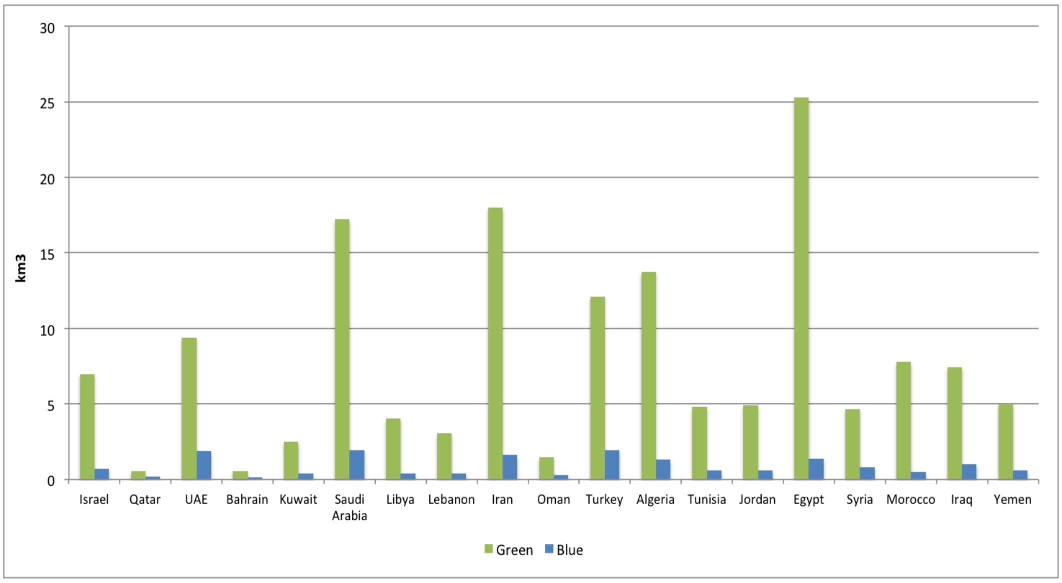
In order to answer this question, this section will, first, provide an analysis of the green and blue virtual water 'imports' and 'exports' in the different MENA economies; and secondly, identify the region's 'net importers' in green and blue water. In the Figures that follow, the MENA countries are ranked according their Human Development Index.

Figure 7.24 shows the virtual water 'imports' of the MENA economies, averaged over the period 1986-2010, by differentiating the source of water 'embedded' in the traded agricultural products. Green water dominates virtual water 'imports' in all the MENA economies. Each country 'imports', on average, 87% green water and 13% blue water.

As shown in the previous sections, *crops* (which include cereals, fruit and vegetables) are the main "conduits" of virtual water 'inflows' in the region. The total volumes and percentage share of cereals, and fruit and vegetables in the average total import of crops at the country level is shown in Table 7.11. Cereals are the main imported crop types in all the MENA economies. The GCC countries (Bahrein, Kuwait, Oman, Qatar and the UAE) and Lebanon are exceptions, with imports of fruit and vegetables ranging between 50% and 70% of total crop imports.

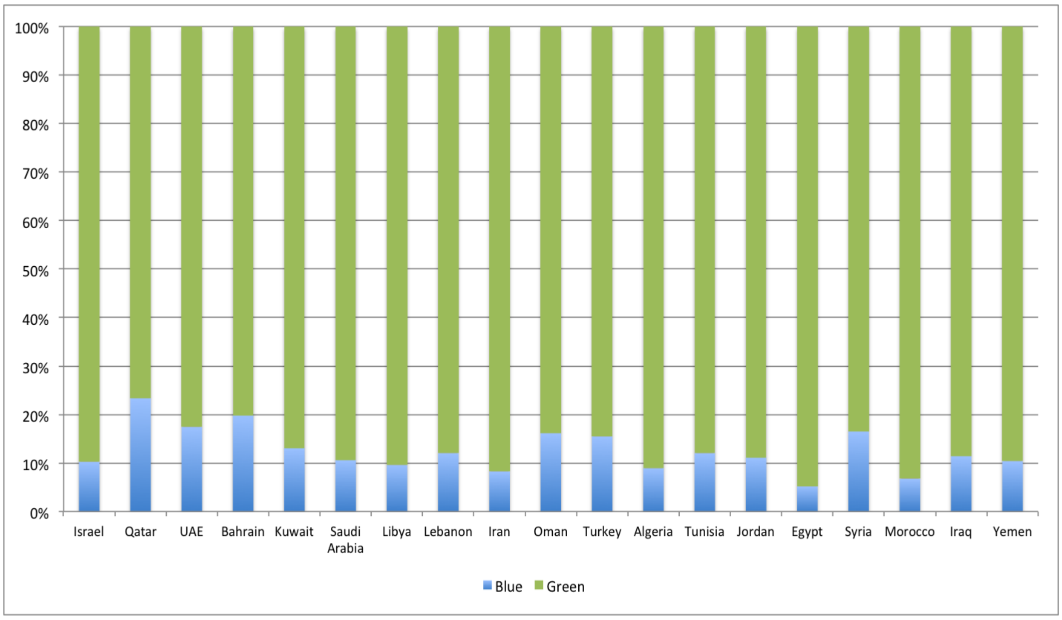
The largest virtual water 'importer' in the region is Egypt, followed by Iran, Saudi Arabia, Algeria and Turkey (between 10 and over 25 km^3 per year each). Saudi Arabia, Egypt and Algeria are the largest importers of cereals in the region, accounting for, respectively, 13%, 15% and 11% of the MENA total import of cereals. Saudi Arabia is, after the UAE, the largest MENA importer of fruit and vegetables (19% of the region's total imports of crops) (Table 7.11 and 7.12). Iran, Egypt and Turkey are the most populated countries in the region, with an average population of 60 Million each, over the period considered (1986-2010) (World Bank 2014). The volumes of virtual water 'imports' in these two countries are thus largely determined by the size of their populations.

Figure 7.24 Virtual water 'imports' in the MENA economies by source of agricultural water: total volumes (average 1986-2010)[64]



Source: Elaboration based on Tamea et al. 2013 and Carr et al. 2013

Figure 7.25 Green and blue virtual water 'imports' in the MENA economies: percentage shares (average 1986-2010)[65]



Source: Elaboration based on Tamea et al. 2013 and Carr et al. 2013

[64] Average is calculated over the 25 years.

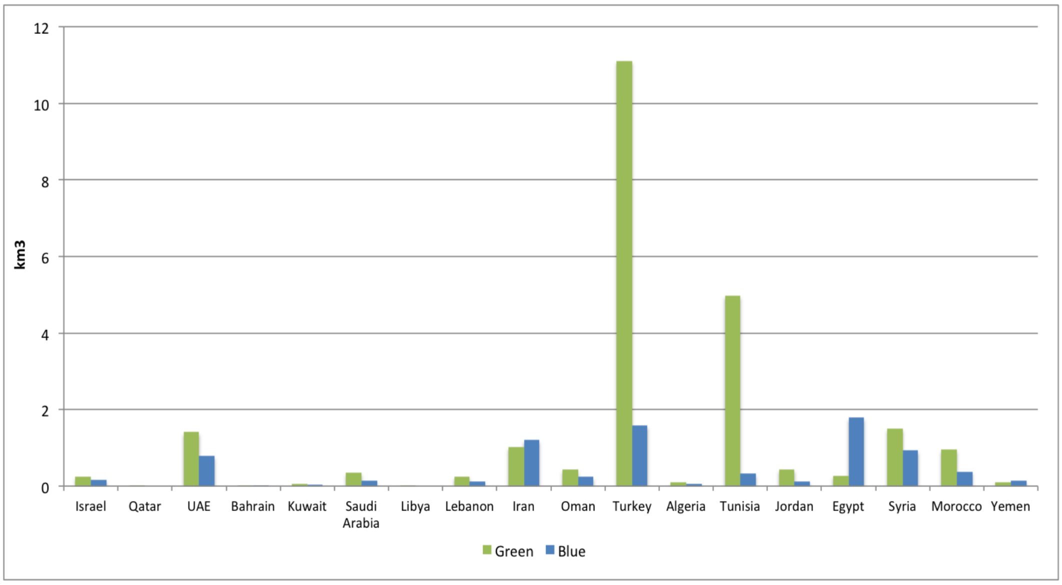
[65] Percentage values refer to the average of the years 1986-2010.

Figure 7.26 shows the virtual water ‘exports’ of the MENA economies, averaged over the period 1986-2010, by differentiating the source of water ‘embedded’ in the traded agricultural products. Green water dominates virtual water ‘exports’ in all the MENA economies, with the exception of Egypt, Iran, Yemen and Bahrein. The percentage share of blue virtual water in ‘exports’ is far higher than in ‘imports’ (Figure 7.27). Each country ‘exports’, on average, 61% green water and 39% blue water. As shown in the previous sections, the MENA exports are mainly associated with trade in crops, which include cereals, fruits and vegetables.

The largest ‘exporter’ of green water in the region is Turkey (about 12 km^3 per year), followed by Tunisia (<5 km^3 per year). Virtual water ‘exports’ from these two countries is associated with the export of crops, especially fruit and vegetables, which account for 90% of crop exports at the country level. Turkey is by far the largest exporters of both cereals and fruit and vegetables in the region, which account, respectively, for 37% and 40% of the MENA total exports of these products. Turkey also ‘export’ substantial volumes of green virtual water as ‘embedded’ in lux-foods. Green water ‘exports’ are below 2 km^3 per year in all the rest of the MENA economies.

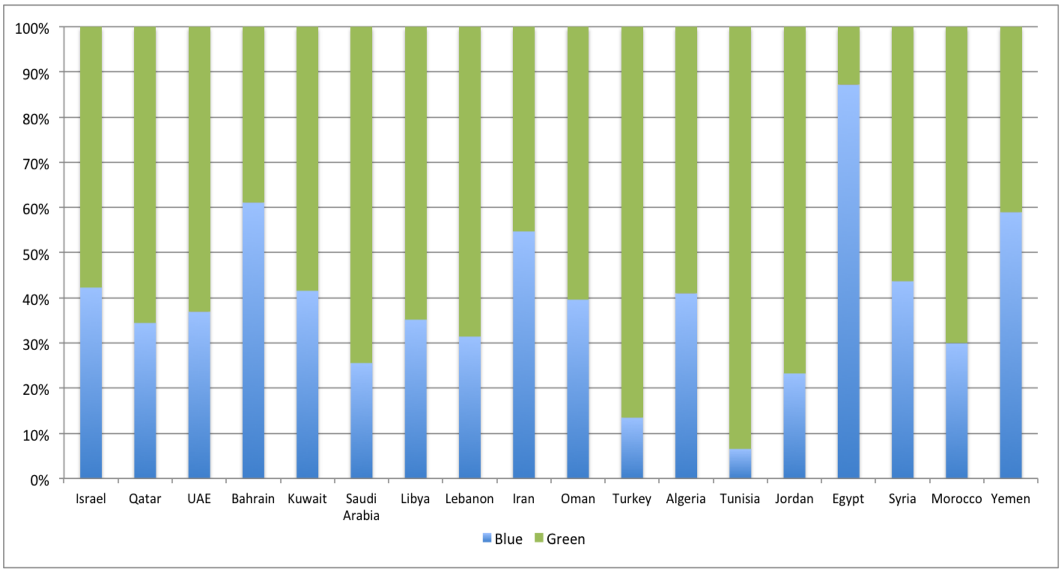
The largest blue water ‘exporter’ is Egypt, mainly as a result of the export of crops (cereals in particular) and non-edible agricultrual goods. Cereal exports from Egypt account for about 17% of the region’s total export of cereals. Turkey is the second largest blue virtual water ‘exporter’ in the region as ‘embedded’ in crops (mainly fruit and vegetables). The ‘export’ of blue virtual water is also high, relatively to green water ‘exports’ in Bahrain, Iran and Yemen. Blue virtual water ‘exports’ from these countries are mainly associated with crops. Virtual water ‘exports in Iran are almost exclusively of fruit and vegetables (98%), accounting for 13% of the region’s total exports in these products. Yemen and Bahrain mainly export fruit and vegetables (>85% of crop exports at the country level).

Figure 7.26 Virtual water 'exports' in the MENA economies by source of agricultural water: total volumes (average 1986-2010)[66]



Source: Elaboration based on Tamea et al. 2013 and Carr et al. 2013

Figure 7.27 Green and blue virtual water 'exports' in the MENA economies: percentage shares (average 1986-2010)[67]



Source: Elaboration based on Tamea et al. 2013 and Carr et al. 2013

[66] Average is calculated over the 25 years.

[67] Percentage values refer to the average of the years 1986-2010.

Table 7.11 Imports and exports of cereals and fruits & vegetables in the MENA countries: import and export value (average 1986-2010). *Source: Elaboration based on FAOSTAT 2013*

	IMPORTS				EXPORTS			
	Cereals [Thousand US$]	**Share in total imports**	**Fruits & Vegetables** [Thousand US$]	**Share in total imports**	**Cereals** [Thousand US$]	**Share in total exports**	**Fruits & Vegetables** [Thousand US$]	**Share in total exports**
Algeria	1,274,279	84%	243,382	16%	848	3%	31,986	97%
Bahrain	39,606	30%	90,971	70%	587	11%	4,676	89%
Egypt	1,639,505	87%	237,399	13%	148,898	29%	358,076	71%
Iraq	804,721	81%	190,281	19%	6,961	24%	21,702	76%
Iran	1,286,717	90%	149,864	10%	14,885	2%	874,239	98%
Israel	434,706	65%	234,404	35%	2,166	0%	688,549	100%
Jordan	302,405	72%	118,976	28%	3,855	2%	182,600	98%
Kuwait	174,494	41%	246,199	59%	4,520	28%	11,769	72%
Lebanon	139,880	45%	168,142	55%	3,493	4%	93,724	96%
Libya	439,173	80%	111,767	20%	99	2%	6,188	98%
Morocco	667,683	89%	79,549	11%	16,443	2%	692,011	98%
OPC	92,253	64%	51,680	36%	1,458	5%	25,121	95%
Oman	138,211	48%	149,326	52%	23,086	49%	23,795	51%
Qatar	66,368	41%	94,549	59%	639	40%	958	60%
Saudi Arabia	1,475,402	65%	804,139	35%	62,235	26%	178,786	74%
Syria	299,731	76%	96,790	24%	75,512	18%	349,959	82%
Tunisia	366,736	89%	43,366	11%	13,678	10%	125,185	90%
Turkey	513,129	72%	199,046	28%	323,800	11%	2,624,741	89%
UAE	513,604	38%	830,507	62%	167,873	42%	230,434	58%
Yemen	438,238	87%	64,291	13%	4,169	15%	23,274	85%
TOT	**11,106,843**	**73%**	**4,204,628**	**27%**	**875,204**	**12%**	**6,547,772**	**88%**

Table 7.12 Imports and exports of cereals and fruits & vegetables in the MENA countries: percentage share in the region's total imports and exports (average 1986-2010)

	IMPORTS		EXPORTS	
	CEREALS [% of MENA total import of cereals]	**FRUIT & VEGETABLES** [% of MENA total import of fruit & vegetables]	**CEREALS** [% of MENA total export of cereals]	**FRUIT & VEGETABLES** [% of MENA total export of fruit & vegetables]
Algeria	11%	6%	0%	0%
Bahrain	0%	2%	0%	0%
Egypt	15%	6%	17%	5%
Iraq	7%	5%	1%	0%
Iran	12%	4%	2%	13%
Israel	4%	6%	0%	11%
Jordan	3%	3%	0%	3%
Kuwait	2%	6%	1%	0%
Lebanon	1%	4%	0%	1%
Libya	4%	3%	0%	0%
Morocco	6%	2%	2%	11%
OPC	1%	1%	0%	0%
Oman	1%	4%	3%	0%
Qatar	1%	2%	0%	0%
Saudi Arabia	13%	19%	7%	3%
Syria	3%	2%	9%	5%
Tunisia	3%	1%	2%	2%
Turkey	5%	5%	37%	40%
UAE	5%	20%	19%	4%
Yemen	4%	2%	0%	0%
TOT	**100%**	**100%**	**100%**	**100%**

Source: Elaboration based on FAOSTAT 2013

7.5 Conclusions

This chapter has provided the first comprehensive analysis of the green and blue virtual water 'trade' implicit in agricultural commodity trade in the MENA region over the past two and a half decades. It has highlighted the importance of soil water by showing that it is the main source of agricultural water 'embedded' in agricultural commodity trade both globally and in the MENA. This source of water is generally ignored by those making water policy as well as by water users in the region. The analysis conducted has also shown that the MENA countries rely on blue water resources relatively more than their virtual water ‘import’ trade partners. The proportion of blue water ‘embedded’ in the MENA export is far higher than in the region’s import of agricultural products.

The chapter also demonstrated that the MENA blue virtual water 'import' trade partners, which include also MENA economies, include both food-water challenged countries as well as countries affected by blue water scarcity. These countries are Pakistan, India, Iran, Syria, Lebanon, USA, and Spain. It was demonstrated that crops dominate both the MENA 'import' and 'export' of green and blue water. Blue water is an important source of water 'embedded' in the MENA import of lux-foods and animal products, as well as in the MENA exports of non-edible commodities.

Finally, it was shown that green water is not only the main source of water 'embedded' in the MENA imports of agricultural products, which mainly originate from *outside* the region, but also the largest share of average virtual water 'exports' at the country level. However, ‘exported’ blue water volumes are quite high in a number of countries in the region. The largest blue water ‘exporter’ in the region is Egypt. The percentage share of blue water exceeds 50% of total virtual water ‘exports’ in Bahrain, Iran and Yemen.

8. Conclusions and future research directions

8.1 Introduction

The purpose of this study was to develop an understanding of the way the MENA countries have coped with water scarcity and achieved food-water security since 1986. The overarching research question was: ***How have the MENA economies coped with water scarcity?*** And more specifically: ***How have these MENA economies achieved their water and food security?*** This final chapter will summarise the scope, objectives and main findings of the study, both in terms of the water available locally for food production and of the 'exogenous' water accessed via international trade that compensates for local deficits. The chapter will also identify the main limitations of the study, and the key areas for the development of future research.

8.2 Scope and objectives of the study

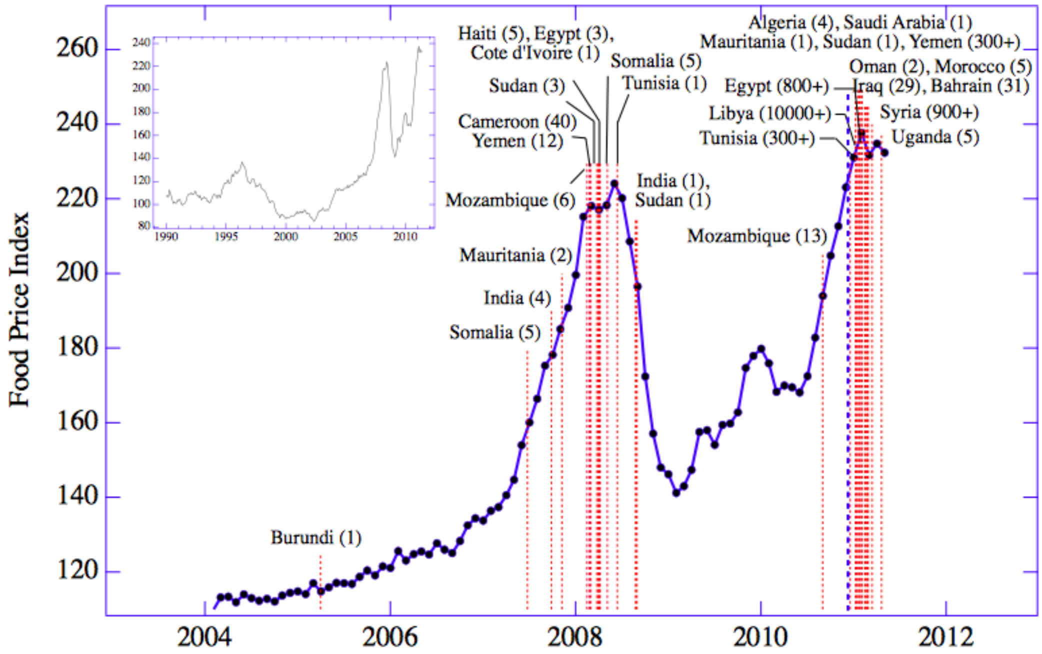
The purpose of the study was to explore the complex and very close relationship between water, food security and trade in the arid and semi-arid Middle East and North African countries. The region is extensive and diverse. It is diverse not only in the scale of the national water deficits but also – and more importantly – in the socio-economic capacity of its economies to cope with the food-related challenges arising from water scarcity. What makes the region's water question particularly urgent is the combination of a number of socio-economic and environmental challenges that are likely to pose further strain on the already stressed water bodies and that also call for the need to promote more sustainable water management. These challenges mainly arise from population growth, changing lifestyles and diets, urbanisation and economic growth, which have exerted pressure on water resources over the past decades – and will do so in the future. There has been an intensification of the competition between different uses during the period addressed in this analysis – 1986 to 2010.

All the region's economies – in some of their areas – endure arid and semi-arid climatic conditions and have very limited water resource endowments. Water problems in the region are not only rooted in physical scarcity, but also in the way resources are allocated, used and managed. The water scarcity predicament of the MENA region has been compounded by serious water management problems, such as over-exploitation of aquifers, deteriorating water quality, unreliable water supplies, and sub-optimal irrigation services. About 85% of the MENA blue water is consumed by the agricultural sector, competing with other uses that would yield much 'more value per drop'. The region has limited soil water resources, which are however ignored by policy-makers and used far below their potential. One of the major aims of the study has been to shed light on this pivotal source of economic and social security in the MENA countries.

Since the largest share of societal water consumption is that required for food production, it is of paramount importance to understand how the MENA economies will secure their populations' needs in the next decades. The region's economies are already overwhelmingly dependent on food imports. This dependency is also likely to increase in the future, as local food-water resources are not sufficient to ensure the production of a balanced diet for their populations, as shown in the analytical Chapter 5. Current and future tensions in the region over food-water are inevitable.

The recent political developments across the region's countries have highlighted the critical role that food security plays in shaping the political and social stability of the area (Breisinger *et al.* 2011; Woertz 2011; Zurayk 2011). In net food-importing countries, such as the MENA economies, political systems are perceived by society to play a critical role in food security. The ability to provide accessible and sufficient food is crucial for the maintenance of political systems. Perception of threats to food security, coupled with other factors, has been a significant determinant of the MENA protests (Lagi *et al.* 2011). As shown in Figure 8.1, the 2008 riots and 2011 protests spread across the MENA region (whose beginning dates is indicated by the red dashed vertical lines) coincided with sharp peaks in international food prices. It should be noted that grain prices have fallen substantially since the 2011 peak and are continuing to fall.

Figure 8.1 Food prices and social unrest in the MENA and other economies (2004-2012)



Note: The Figure shows the FAO Food Price Index from January 2004 to May 2011. Red dashes lines are drawn in correspondence with the beginning of protests in the MENA region and other countries. The numbers reported in parenthesis indicate the overall death toll associated with each protest. Inset on the top left shows the FAO Food Price Index from 1990 to 2011.

Source: Lagi *et al.* (2011: 3)

In this context, one of the main aims of the study has been to increase understanding of the role that *trade* has played over the past 25 years in ameliorating of water deficits the MENA economies. The study has explored the water-food-trade nexus using the lens of virtual water, that is, the *fil rouge* guiding the whole analysis. The virtual water concept was deployed in order to account for the water 'embedded' in the commodities that are exchanged between nations. 'Trade' in virtual water is much more feasible and affordable than transferring *real* water resources, and makes it possible for water-scarce countries to effectively cope with poor resource endowments. It also enables policy-makers to de-emphasise the scope of the water challenge and to avoid politically-hazardous reforms in the water sector. The recognition of the *political nature* of water resources in the MENA, highlighted by Allan in 2001, has been taken as a point of departure for the framing of the study. The study has provided evidences that the political economy of water resources in the MENA is dominated by the region's engagement in the political economy of international trade in food commodities by analysing food and virtual water 'trade' in a new and comprehensive way.

By using the theory of Social Adaptive Capacity, the study also showed that it is possible to cope with first-order resource scarcities by means of second-order resources. The more 'adaptive' economies, such as Israel and the rentier oil economies, such as the GCC countries, have been water secure, despite negligible endowments of both green and blue water. It has been shown that water scarcity does *not* necessarily lead to water insecurity, unless it is coupled with low socio-economic adaptiveness. Moreover, diverse and strong economies also have the potential to overcome water resource constraints by allocating and managing water resources better, as shown by the case of Israel.

The next sections revisit the research questions, and summarise the main contributions as well as the limitations of the study. Future research directions will also be identified.

8.3 Revisiting the research questions

The study aimed at contributing to the existing literature on the MENA water security by exploring the water-food-trade nexus of the region's economies in a *comprehensive* way. The overarching research question of the study – that is, ***How has the MENA region coped with water scarcity?*** And more specifically: ***How***

have these MENA economies achieved their water and food security*?* – has been addressed in the three analytical Chapters 5, 6 and 7. The main findings of these chapters can be summarised as follows.

The first analytical chapter (Chapter 5) has provided an assessment of food-water resource availability in the MENA region, addressing the first subsidiary question of the study (***To what extent can local water resources meet the food-water requirements of the MENA political economies?***). The assessment included the *full* water resources available for food production in the MENA countries, that is not only the water contained in surface and groundwater bodies, but also soil (green) water. Green water has never been taken into account in the national water budgets of the MENA economies, although it underpins long established, but sub-optimal, dryland winter farming and grazing in the region. In Chapter 5 it has been argued that incorporating the concept of green water can much better inform effective water resources management and planning in the region (Zeitoun *et al*. 2008).

Within the limits of the study, it has been shown that green water provides a quite substantial source of agricultural water in a number of countries in the region (namely, Iran, Turkey and Syria in the Near East; Morocco, Tunisia and Algeria in North Africa). It has been also demonstrated that, with the exception of Turkey, *all* the MENA countries have faced food-water scarcity, although to different extents, as the water available locally has not met water requirements for local food security. Water scarcity is particularly severe in Saudi Arabia, Jordan, Yemen, Israel and Kuwait. These countries face very high rates of population growth. Food-water availability, considered as the availability of both green and blue water resources for food production, has also been related to second-order (socio-economic) resource availability at the country level. In considering the *full* food-water resources available, the study has overcome a major limitation of the analysis carried out by Earle (2001) for some of the region's economies. The dataset deployed however did not enable 1) to assess water availability for food production through time, as data refer to the average water availability per country over the period 1971-2000; 2) to assess water scarcity at sub-national scale.

The second analytical chapter (Chapter 6) has investigated the extent to which the MENA political economies depend on virtual water 'imports' to secure their population's food needs. It answered the second subsidiary question of the study (***What has been the role of international trade in meeting the water requirements of the MENA economies?*** And, more specifically: ***To what extent have the MENA countries relied on virtual water 'trade' to secure their food-water needs?***). The chapter has provided a comprehensive assessment of the MENA virtual water 'trade' over the past 25 years. The assessment has been original for *four* main reasons.

First, the temporal dynamics and evolution of virtual water 'trade' in agricultural commodities in *all* the MENA countries have been examined over a 25-years time span, rather than as an average over an identified number of years. The proposed analysis is based on yearly data of trade of agricultural goods (309 items) exchanged across the world, as provided by FAOSTAT, and on average virtual water content of agricultural commodities over a 10-years period (1996-2005), as provided by Mekonnen and Hoekstra (2010b). The temporal evolution of virtual water 'trade' was analysed and linked to other environmental and socio-economic dynamics faced by the region. The chapter showed that the MENA face rapidly increasing populations and changes in dietary preferences, which have driven, respectively, an increase in the water footprint of agricultural consumption (+77%) and virtual water 'imports' (+162%) over the period 1986-2010. The MENA countries have the second highest virtual water 'import' per capita in the world (446 m^3 per capita per year), after the EU. It was also shown that the increase in virtual water 'imports' was enabled by a downward trend in food prices, which made the import of food an economically efficient solution to the region's water deficit until the middle of the first decade of the twenty-first century. Virtual water 'imports' may have been, however, overestimated in the countries where re-exports of agricultural goods is substantial, due to data availability.

Secondly, the study also identified the main virtual water 'trade' partners of the MENA region. It was shown that virtual water 'imports' are mainly extra-regional, whereas virtual water 'exports' are intra-regional to a significant extent. It was revealed that some of the MENA blue virtual water 'trade' partners suffer from food-water scarcity or blue water scarcity of local river basins. These countries include USA, Spain, Syria, Iran, Pakistan, India and Lebanon. The study did not account for intra-regional virtual water 'flows'.

Thirdly, it was demonstrated that food products, crops in particular, account for the largest share of virtual water 'imports' and also of 'exports' (over 90%). The dependency indicator deployed in Chapter 6 proved possible to appraise the MENA economies' dependency on virtual water 'imports' to secure the food needs of their populations. Some limitations concerning this indicator have been identified and are mainly related to the impossibility of taking into accounting of commodity re-exports and productivity of local water resources. A strong correlation was noted between high virtual water 'import' dependency, socio-economic diversification and adaptiveness, food security and mineral resource endowments.

Finally, it has been shown that the most green and blue water scarce economies in the region (such as Saudi Arabia, Jordan, Israel and Kuwait) are also the most dependent on virtual water 'imports' from the global system. All these countries, with the exception of Jordan, are *food secure*. The socio-economic diversification of these countries will determine the extent to which they will be able to continue to cope with water scarcity by means of virtual water 'trade'. The cost of engaging in trade, the nature of national economic objectives and political considerations are all factors that determine the extent to which international trade can be used to respond to water scarcity. These considerations are particularly important in the MENA, especially as half of the region's economies depend on a very few export products (mainly primary products or oil). These countries are thus vulnerable to changes in terms of trade, which affect in turn their capacity to pay for imports, and are also vulnerable to volatility in market prices.

Chapter 7 addressed the third subsidiary question of the study (***To what extent have green and blue water resources underpinned the MENA virtual water 'trade?***). The chapter revealed the sources of water 'embedded' in both the imported and exported agricultural goods, and also provided insights on volumes and origins of these virtual 'flows'. Unravelling the sources of water deployed for agricultural production is important in that it enables consideration of the different opportunity costs and environmental externalities associated with their use. The chapter showed that green water is the main source of virtual water 'embedded' in agricultural commodity trade but that blue water accounts for a substantial proportion of the virtual water 'exported' by the MENA countries. The reliance on this source of water in the MENA exporting countries is relatively higher than that of their virtual water 'import' trade partners. All the region's economies are net green water 'importers'.

The main contributions of the study are summarised in the next section.

8.4 Main contributions of the study

The original contributions of the study can be summarised as follows:

1. The study has provided the first comprehensive analysis of the MENA food-water scarcity and has confirmed the unprecedented role of green water in the water and food security of the MENA economies. More specifically, it has been shown that:

By considering green water resources – besides blue water – water availability for food production more than doubles in 9 out of 18 MENA countries, namely Morocco, Tunisia and Algeria in North Africa; Iran; Syria, Turkey, Yemen and Jordan in the Near East. Within the limits of the study, it was shown that in half of the region's economies, green water exceeds 50% of total food-water availability. The lowest green water availability is found in Egypt (about 2% of total food-water resources). By highlighting the potential role of green water as a source of food-water, the study calls for a re-thinking of the way water is allocated and managed in the region. In the MENA, as well as across the world, agricultural use of blue water is increasingly at risk due to the high opportunity cost associated with other uses (industrial, service or urban) as well as environmental needs and concerns. These alternative applications yield much more value per drop and typically require the highest quality water, and therefore deliver higher net returns to a population or economy as a whole. This especially applies where non-renewable groundwater resources have been mobilised for agricultural production, as in the case of the Disi pipeline in Jordan (Ferragina and Greco 2008). As argued by Gilmont *et al.* (2015), improving rainfed agriculture would be in contrast to the historic situation where such improvements in soil and water productivity are incorporated *after* the introduction of irrigation and used to redress declines in production. The proposed alternative pathway called for in this study would allow for incremental and sustainable gains in productivity while reducing the medium-long term risk of having to re-engineer an entire agricultural sector. The study has also shown that green water accounts for 90% of the region's total virtual water 'imports', and 74% of the MENA total virtual water 'exports'. Green water is the main source of virtual water 'exports' from the MENA region with almost one third of the region's agricultural exports relying on local blue water resources.

2. The study has analysed the food and virtual water 'trade' of the economies in the region, confirming in unprecedented detail the role of virtual water 'imports' in achieving a version of water and food security. More specifically, the study showed that:

Egypt, Iran and Saudi Arabia, followed by Algeria and Turkey, are the largest gross virtual water 'importers' in the region. Turkey and the UAE, and to a smaller extent, Tunisia, Iran and Syria are the largest gross virtual water 'exporters' in the region. Within the limitations of the data available, it was shown that 'exports' from the UAE are related to a considerable extent to the 're-export' of 'imported' virtual water. All the MENA countries but Tunisia – although to a quite small extent – are net 'importers' of virtual water. The most diversified economies in the region – namely, Israel and the GCC economies – show the highest virtual water net 'imports' in the region.

The effect of virtual water 'trade' can be weighted including consideration of the source of water 'embedded' in traded commodities and the related opportunity costs. The study differentiated the green and blue water resources 'embedded' in the commodities exchanged internationally by the MENA countries. It was shown that each country 'imports', on average over 85% of green water and also 'exports', on average, about 40% of blue water. Crops dominate both virtual water 'imports' and 'exports' in the region. Triangulation revealed that the proportions of green and blue water 'traded' are in line with other studies on international virtual water 'trade' in agricultural commodities.

3. The study has analysed the dependency on *external* water resources of the MENA economies and has confirmed that virtual water 'flows' towards money. More specifically:

By developing a food-water 'import' dependency indicator relating virtual water 'imports' to the water footprint of agricultural consumption, it was possible to show that 15 out of 20 countries in the MENA have dependency ratios exceeding 50%. The dependency on *external* water resources is higher than 50% in the GCC countries, Israel, Lebanon and Jordan. The UAE and Oman have dependency ratios above 100%. A strong correlation between food security, economic diversification and adaptiveness, as well as high dependency on virtual water 'imports' and mineral resource endowments was noticed, showing that virtual water 'flows' towards money. Water scarce countries have been shown to be water secure despite negligible resource endowments. These countries remedy local water deficits by means of second-order resources. Socio-economic diversification is thus crucial in ensuring that the MENA countries will be able to cope with water scarcity and to effectively achieve a version of food security. Virtual water 'imports' can be considered as an *external* source of water, which can also potentially free up local water resources for other uses (e.g. ecosystem, industry, services). For these reasons, this study argues that it is essential that consideration of virtual water 'flows' be given in the development of national water policies.

The study also confirms – much more comprehensively and in much greater detail than any previous study – a number of important conditions, outcomes of existing water allocating and managing outcomes and options:

Trade in virtual water plays a major role in providing the region with water and food security. The economic diversification and strength of an economy is crucial with respect to the accessibility of virtual water in the global commodity trade systems.

Trade plays a key role in food water security. The MENA economies are overwhelmingly dependent on external water resources to meet their populations' needs for food water. The reliance on virtual water has been possible thanks to a favourable downward trend in food prices, which has made it possible to access cheap and abundant food-water from the global system thus alleviating local water deficits as well as the impacts of frequent droughts in the region. However, the increasing instability of the international market and volatility of food prices raise concerns about the sustainability of the virtual water 'solution' for the less diversified and adaptive MENA economies. The variability of international prices of staples impacts severely the rural fragments of society as well as urban poor. In this context, it is important to incorporate the consideration of virtual water 'trade' into national integrated water management strategies, and to implement water demand management measures that make better use of local resources. International food trade can be used in fact as an active policy instrument to moderate crop water depletion and irrigation water demand. Last but not least, it is necessary to diversify exports beyond oil**,** as well as the sources of virtual water 'imports' to reduce risks resulting from international crises, market instability and supply disruptions.

Green water plays a major role in the MENA virtual water 'trade', however blue water constitutes a substantial source of agricultural water in a number of MENA economies.

Virtual water 'trade' in the MENA economies have been dominated by green water, however the blue water component is significant in the virtual water 'exports' from a number of the MENA economies. Blue water use in agriculture yields the lowest value among other uses and is often associated with over-allocation. The highest proportion of virtual water 'exports' is associated with *crops* (about 70%). In some of the MENA economies, the export of cereals is far higher than the export of fruits and vegetables, although the latter would turn water into higher economic value. They have also been low on water-intensity and more suited to water-saving techniques. Shifting production to high-value crops would therefore be beneficial for farmers, increasing incomes without increasing agricultural water consumption.

A more comprehensive approach to allocating and managing water resources is needed.

The research has highlighted the need to adopt a *more comprehensive* approach to allocating and managing water that includes consideration of green water as a major source of agricultural water in addition to virtual water 'flows' in order to inform water policy-making. It has been noted that the invisibility of virtual water 'trade' has lead to procrastination of necessary reforms in the water sector and has made invisible and silent the water security problem in policy discourses (World Water Council 2004). Israel is an exception in this regard (Gilmont 2014a; 2014b). Virtual water 'imports' can be seen as "secret reserves" that might bail out in the short term (Warner 2003; Warner and Johnson 2007).

Incorporating the notion of virtual water 'trade' has the potential to better inform the exchange of goods, diversification of crop production and trade, as well as diet awareness. These findings suggest that it is necessary to consider virtual water 'flows' when devising water and food security policies in the region. The region is and will always be a major importer of food and virtual water. It is thus important to allocate and manage water in a way that maximises economic returns to generate foreign currency reserves to purchase food in the international market. Economic diversification ensures a version of water and food security in the region in a world at peace.

It is very important to incorporate soil water in basin and national water balances to properly evaluate the water and food security of the economies of the MENA region.

The MENA is facing severe water scarcity, which is very closely linked with food security. All the region's economies – with the exception of Turkey – are food-water scarce, as the water available locally is not sufficient to produce a balanced dietary intake for their populations. However, if green water is included in the water resource endowment estimates the MENA food-water predicament is less severe in most economies. Egypt is exceptional in being almost totally dependent on blue water. It is important to highlight the availability of soil water in the MENA economies as policy-makers have ignored this water. The MENA economies need to invest in dryland farming and unlock green water productivity, as it can help meet the future food needs of the region.

8.5 Limitations of the study and future research directions

This final section identifies some limitations of the analysis carried out in this study and also a number of future research directions.

The limitations of the study are mainly four. First, the study addressed the MENA water question in a very diverse region, which includes countries faced with different environmental and socio-economic challenges and with different capacities to cope with them. A second limitation derives from the time boundaries of the research due to data availability, quality and quantity. Water scarcity, for instance, has been expressed as a 30-year annual average per country, thus masking any change in water quantity over time, as well as water scarcity at sub-national scale or in specific years. The drawbacks associated with the conceptualization of green and blue water have been outlined in the Methodological chapter. Some limitations also concern the assessment of the MENA virtual water 'trade'. Trade data from FAOSTAT, used to derive international virtual water 'flows', did not enable in fact tracking of commodity (and virtual water) re-exports – thus bringing about an overestimation of virtual water 'imports' in the region's commercial hubs. Missing data regarding agricultural commodity trade in some years or for the whole timespan considered (e.g. Iraq) are also acknowledged and have been dealt with as specified in the Methodology chapter. Inter-country virtual water 'trade' was also not accounted for due to data limitations. Triangulation has been applied rigorously to reduce any bias or drawbacks in the data.

Some directions for future research are also identified. The identified future research paths regarding the water scarcity assessment in the MENA (Chapter 5) include consideration of the issues identified below:

- How different income levels (both within and between countries) affect the demand for food and the composition of the diet;
- How different proportions of vegetal and animal products in the targeted diet affect water requirements. Another important aspect would be the consideration of country-specific dietary habits, which determine, to a large extent, local water requirements. The production of beef, for instance, is far more water intensive than the production of chicken meat;
- How green and blue water availability changed over the past decades, both as a result of withdrawals as well as changes in climate affecting evapotranspiration, precipitation etc.;
- How changes in the productivity of green and/or blue water would be reflected in different water requirement scenarios;

- Identify the MENA countries' future water gaps considering future changes in water availability due to climate change and demographic trends.

The study also provided a new and in depth analysis of the role that virtual water 'imports' play in mitigating MENA water scarcity by providing a *comprehensive* analysis of virtual water 'trade' in the region as a whole (Chapter 6 and 7). Pathways for future research include:

- Consideration of environmental sustainability and incorporation of water quality concerns;
- Consideration of *crop water requirements* in a dynamic fashion, that is, by taking into account of their inter-annual variability due to climate, as well as to technological/productivity changes;
- Consideration of virtual water 'trade' in manufactured goods, although they are far less water-intensive than agricultural products;
- Consideration of virtual water 'trade' impacts at the scale of local river-basins;
- Consideration of virtual water re-exports, that is, the amount and sources of water 'embedded' in the 'export' of previously 'imported' virtual water. All virtual water 'trade' assessments based on FAO trade data are affected by this limitation;
- Differentiation between blue virtual water 'exports' sources by renewable water resources and non-renewable water resources;
- Analysis of how population changes and increase in lifestyles will affect food demands and virtual water 'trade' in the MENA.

Building on the analysis carried out in this study, the author has also identified specific future research directions addressing the MENA water security question:

- Publication of a book, for which the author has received an expression of interest by the publishing house IB Tauris;

- Publication of peer-reviewed articles and policy papers on the basis of the main findings of the study (more details on this aspect have been provided in the methodology Chapter 4);
- Publication of an article on *decoupling and virtual water 'trade'* in some selected MENA economies (possibly, Egypt, Jordan and Israel), co-authored with Dr Michael Gilmont;
- Presentation of the research findings in international conferences and meetings (more details on this aspect have been provided in the methodology Chapter 4);
- Application for a EU-funded Marie Curie fellowship in an international university or research institution over the next 12 months, in order to keep on working on water and food security in the MENA or the Mediterranean region.

8.6 Conclusion

Water and food security is, and will be in the future, one of the most salient features of the MENA region landscape, from the economic, social and political perspectives. The MENA region faces a number of serious challenges that generate contentious discourses, which make addressing the region's water resources predicament particularly urgent. A number of structural factors are likely to continue to aggravate issues of food security as well as food sovereignty.

The study aimed to contribute an understanding of how the MENA economies achieve water and food security by addressing the "knowledge problem" identified by Allan in 2001. The study has provided a comprehensive version of the region's hydrology as well as to expose the invisible 'flows' of water underpinning the food security of the MENA populations. In pursuing these aims, the study informs regional water thinking and policy by providing policy-relevant insights. The extent to which the people and leaders in the region will recognise the environmental and economic nature of their water resources will determine the future of the MENA region. Consideration of such perspectives must always be subject to discursive political processes that recognises the value of water.

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Appendices

A. List of commodities and categorisation

The table below shows the complete list of the 309 items considered in the analysis, with the corresponding category, and presence/absence in the sub-list of items considered for domestic production (only primary crop products and derived animal products are included, if present in the complete list).

A1. List of commodities

Item	Category	In production
Wheat	crops	Yes
Flour of Wheat	crops	No
Macaroni	crops	No
Bread	crops	No
Rice, paddy	crops	Yes
Rice Husked	crops	No
Rice Milled	crops	No
Rice Broken	crops	No
Rice Flour	crops	No
Barley	crops	Yes
Barley Pearled	crops	No
Barley Flour and Grits	crops	No
Malt	crops	No
Beer of Barley	lux-foods	No
Maize	crops	Yes
Flour of Maize	crops	No
Maize oil	crops	No
Rye	crops	Yes
Flour of Rye	crops	No
Oats	crops	Yes
Oats Rolled	crops	No
Millet	crops	Yes
Sorghum	crops	Yes
Buckwheat	crops	Yes

Quinoa	crops	yes
Fonio	crops	yes
Triticale	crops	yes
Canary seed	crops	yes
Mixed grain	crops	yes
Cereals, nes	crops	yes
Potatoes	crops	yes
Potatoes Flour	crops	no
Frozen Potatoes	crops	no
Potato Offals	crops	no
Tapioca of Potatoes	crops	no
Sweet potatoes	crops	yes
Cassava	crops	yes
Flour of Cassava	crops	no
Tapioca of Cassava	crops	no
Cassava Dried	crops	no
Cassava Starch	crops	no
Yautia (cocoyam)	crops	yes
Taro (cocoyam)	crops	yes
Yams	crops	yes
Roots and Tubers, nes	crops	yes
Flour of Roots and Tubers	crops	no
Sugar cane	lux-foods	yes
Sugar beet	lux-foods	yes
Maple Sugar and Syrups	lux-foods	yes
Sugar crops, nes	lux-foods	yes
Sugar Raw Centrifugal	lux-foods	no
Sugar Refined	lux-foods	no
Molasses	lux-foods	no
Other Fructose and Syrup	lux-foods	yes
Sugar, nes	lux-foods	no
Sugar flavoured	lux-foods	no
Glucose and Dextrose	lux-foods	yes
Beans, dry	crops	no
Broad beans, horse beans, dry	crops	yes
Peas, dry	crops	no
Chick peas	crops	yes
Cow peas, dry	crops	yes
Pigeon peas	crops	yes
Lentils	crops	yes
Bambara beans	crops	yes
Vetches	crops	yes
Lupins	Crops	yes
Pulses, nes	Crops	yes
Flour of Pulses	Crops	no

Brazil nuts, with shell	Crops	yes
Cashew nuts, with shell	Crops	yes
Chestnuts	Crops	yes
Almonds, with shell	Crops	yes
Walnuts, with shell	Crops	yes
Pistachios	Crops	yes
Kolanuts	Crops	yes
Hazelnuts, with shell	Crops	yes
Arecanuts	lux-foods	yes
Almonds Shelled	Crops	no
Walnuts Shelled	Crops	no
Hazelnuts Shelled	Crops	no
Nuts, nes	Crops	yes
Prepared Nuts (Exc.Groundnuts)	Crops	no
Soybeans	Crops	yes
Soybean oil	Crops	no
Cake of Soybeans	Crops	no
Soya Sauce	Crops	no
Soya Paste	Crops	no
Soya curd	Crops	no
Groundnuts, with shell	Crops	yes
Groundnuts Shelled	Crops	no
Groundnut oil	Crops	no
Coconuts	Crops	yes
Copra	Crops	no
Coconut (copra) oil	Crops	no
Palm kernels	Crops	yes
Palm oil	Crops	no
Palm kernel oil	Crops	no
Cake of Palm Kernel	Crops	no
Olives	Crops	yes
Olive oil, virgin	Crops	no
Olives Preserved	Crops	no
Karite Nuts (Sheanuts)	Crops	yes
Butter of Karite Nuts	Crops	no
Castor oil seed	non-edible	yes
Oil of Castor Beans	non-edible	no
Sunflower seed	Crops	yes
Sunflower oil	Crops	no
Sunflower Cake	non-edible	no
Rapeseed	crops	yes
Rapeseed oil	crops	no
Cake of Rapeseed	non-edible	no
Olive Residues	non-edible	no

Oil of Jojoba	lux-foods	yes
Safflower seed	crops	yes
Sesame seed	crops	yes
Sesame oil	crops	no
Mustard seed	crops	yes
Poppy seed	crops	yes
Melonseed	crops	yes
Cottonseed	non-edible	yes
Cottonseed oil	crops	no
Cake of Cottonseed	non-edible	no
Linseed	non-edible	yes
Linseed oil	non-edible	no
Cake of Linseed	non-edible	no
Hempseed	crops	yes
Oilseeds, Nes	crops	yes
Oil of vegetable origin, nes	crops	no
Cabbages and other brassicas	crops	yes
Artichokes	crops	yes
Asparagus	crops	yes
Lettuce and chicory	crops	yes
Spinach	crops	yes
Tomatoes	crops	yes
Tomatojuice Concentrated	crops	no
Juice of Tomatoes	crops	no
Paste of Tomatoes	crops	no
Tomato Peeled	crops	no
Cauliflowers and broccoli	crops	yes
Pumpkins, squash and gourds	crops	yes
Cucumbers and gherkins	crops	yes
Eggplant-baseds (aubergines)	crops	yes
Chillies and peppers, green	crops	yes
Onions (inc. shallots), green	crops	yes
Onions, dry	crops	no
Garlic	crops	yes
Beans, green	crops	yes
Peas, green	crops	yes
String beans	crops	yes
Carrots and turnips	crops	yes
Okra	crops	yes
Maize, green	crops	yes
Sweet Corn Frozen	crops	yes
Veg.Prod.Fresh Or Dried	crops	no
Carobs	crops	yes
Vegetables fresh nes	crops	yes
Juice of Vegetables Nes	crops	no

Vegetables Dehydrated	crops	no
Vegetables in Vinegar	crops	no
Vegetables Preserved Nes	crops	no
Vegetable Frozen	crops	no
Bananas	crops	yes
Plantains	crops	yes
Oranges	crops	yes
Orange juice, single strength	crops	no
Tangerines, mandarins, clem.	crops	yes
Lemons and limes	crops	yes
Grapefruit (inc. pomelos)	crops	yes
Juice of Grapefruit	crops	no
Citrus fruit, nes	crops	yes
Citrus juice, single strength	crops	no
Apples	crops	yes
Cider Etc	crops	no
Apple juice, single strength	crops	no
Pears	crops	yes
Apricots	crops	yes
Dry Apricots	crops	no
Sour cherries	crops	yes
Cherries	crops	yes
Peaches and nectarines	crops	yes
Plums and sloes	crops	yes
Plums Dried (Prunes)	crops	no
Stone fruit, nes	non-edible	yes
Strawberries	crops	yes
Raspberries	crops	yes
Gooseberries	crops	yes
Currants	crops	yes
Blueberries	crops	yes
Cranberries	crops	yes
Berries Nes	crops	yes
Grapes	crops	yes
Raisins	crops	no
Grape Juice	crops	no
Must of Grapes	lux-foods	no
Wine	lux-foods	no
Vermouths and Similar	lux-foods	no
Marc of Grapes	lux-foods	no
Watermelons	Crops	yes
Other melons (inc.cantaloupes)	Crops	yes
Figs	Crops	yes
Mangoes, mangosteens, guavas	Crops	yes

Avocados	Crops	yes
Pineapples	Crops	yes
Juice of Pineapples	Crops	no
Dates	Crops	yes
Cashew apple	Crops	yes
Kiwi fruit	Crops	yes
Papayas	Crops	yes
Fruit, tropical fresh nes	Crops	yes
Fruit Tropical Dried Nes	Crops	no
Fruit Fresh Nes	Crops	yes
Fruit Juice Nes	crops	no
Coffee, green	lux-foods	yes
Coffee Roasted	lux-foods	no
Cocoa beans	lux-foods	yes
Cocoa Paste	lux-foods	no
Cocoahusks;Shell	non-edible	no
Cocoa Butter	lux-foods	no
Cocoapowder and Cake	lux-foods	no
Chocolate Prsnes	lux-foods	no
Tea	lux-foods	yes
Hops	lux-foods	yes
Pepper (Piper spp.)	lux-foods	yes
Chillies and peppers, dry	lux-foods	no
Vanilla	lux-foods	yes
Cinnamon (canella)	lux-foods	yes
Cloves	lux-foods	yes
Nutmeg, mace and cardamoms	lux-foods	yes
Anise, badian, fennel, corian.	lux-foods	yes
Ginger	lux-foods	yes
Spices, nes	lux-foods	yes
Peppermint	crops	yes
Cotton lint	non-edible	yes
Cotton Carded,Combed	non-edible	no
Cotton Waste	non-edible	no
Cotton Linter	non-edible	yes
Flax fibre and tow	non-edible	yes
Flax Tow Waste	non-edible	no
Hemp Tow Waste	non-edible	yes
Jute	non-edible	yes
Other Bastfibres	non-edible	yes
Ramie	non-edible	yes
Sisal	non-edible	yes
Agave Fibres Nes	non-edible	yes
Manila Fibre (Abaca)	non-edible	yes
Fibre Crops Nes	non-edible	yes

Tobacco, unmanufactured	lux-foods	yes
Natural rubber	non-edible	yes
Cattle	animal product	no
Cattle meat	animal product	yes
Offals of cattle, edible	animal product	yes
Meat-Cattle, boneless	animal product	yes
Meat of Beef,Drd, Sltd,Smkd	animal product	yes
Sausage Beef and Veal	animal product	yes
Cow milk, whole, fresh	animal product	yes
Butter Cow Milk	animal product	no
Milk Skm of Cows	animal product	no
Milk Whole Cond	animal product	no
Whey Condensed	animal product	no
Yoghurt	animal product	no
Butterm.,Curdl,Acid.Milk	animal product	no
Milk Whole Dried	animal product	no
Milk Skimmed Dry	animal product	no
Processed Cheese	animal product	no
Prod.of Nat.Milk Constit	animal product	no
Cattle hides	non-edible	yes
Hides Wet Salted Cattle	non-edible	no
Hidesdry S.Cattle	non-edible	no
Sheep	animal product	no
Sheep meat	animal product	yes
Offals of Sheep,Edible	animal product	yes
Cheese of Sheep Milk	animal product	yes
Skins Nes Sheep	non-edible	yes
Skins With Wool Sheep	non-edible	yes
Goats	animal product	no
Goat meat	animal product	yes
Offals of Goats, Edible	animal	yes

	product	
Cheese of Goat Mlk	animal product	yes
Goatskins	non-edible	yes
Pigs	animal product	no
Pig meat	animal product	yes
Offals of Pigs, Edible	animal product	yes
Fat of Pigs	animal product	yes
Bacon and Ham	animal product	no
Sausages of Pig Meat	animal product	no
Prep of Pig Meat	animal product	no
Chickens	animal product	yes
Hen eggs, in shell	animal product	yes
Eggs Liquid	animal product	no
Eggs Dried	animal product	no
Duck meat	animal product	yes
Goose and guinea fowl meat	animal product	yes
Turkey meat	animal product	yes
Other bird eggs,in shell	animal product	yes
Horses	animal product	no
Horse meat	animal product	yes
Hair of Horses	non-edible	yes
Hides Wet Salted Horses	non-edible	no
Hides Dry Slt Horses	non-edible	no
Hides Unsp Horse	non-edible	yes
Asses	animal product	yes
Mules	animal product	yes
Offals other camelids	animal product	yes
Cocoon Unr. and Waste	non-edible	yes
Hair Coarse Nes	non-edible	yes
Food Prep Nes	crops	no

B. Water footprints of national consumption

B1. Water footprint of national consumption by sector (1996-2005)

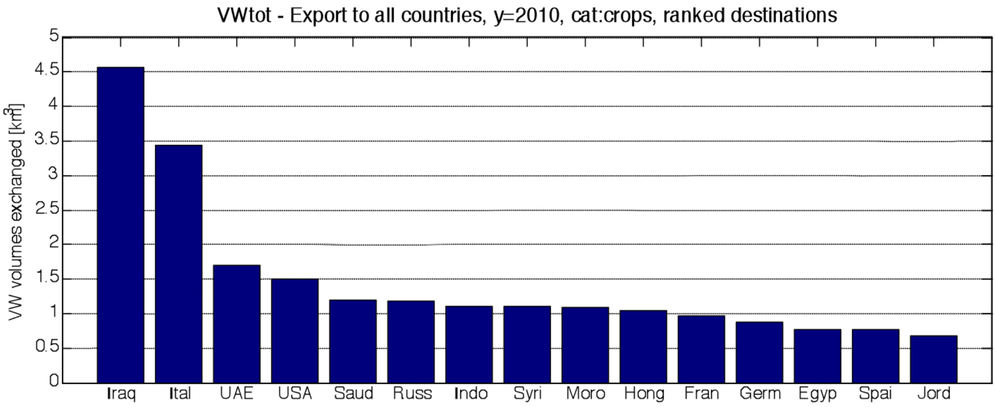
	WF of consumption of agricultural products		**WF of consumption of industrial products**		**WF of domestic consumption**		**Total WF per capita**
	m3/cap/yr	*%*	*m3/cap/yr*	*%*	*m3/cap/yr*	*%*	*m3/cap/yr*
Algeria	1544	97%	14	1%	32	2%	1589
Egypt	1213	90%	53	4%	75	6%	1341
Iran	1755	94%	19	1%	92	5%	1866
Israel	2167	94%	108	5%	28	1%	2303
Jordan	1592	95%	49	3%	37	2%	1678
Kuwait	1833	88%	61	3%	178	9%	2072
Lebanon	1976	94%	88	4%	48	2%	2112
Libya	1902	93%	23	1%	113	6%	2038
Morocco	1684	98%	15	1%	26	2%	1725
Saudi Arabia	1708	92%	40	2%	101	5%	1849
Syria	2001	95%	25	1%	81	4%	2107
Tunisia	2167	98%	23	1%	27	1%	2217
Turkey	1510	92%	70	4%	63	4%	1642
UAE	2645	84%	306	10%	185	6%	3136
Yemen	883	98%	4	0%	15	2%	901
MENA	1772	93%	60	3%	73	4%	1905

Source: Elaboration based on Mekonnen and Hoekstra 2011as

C. Virtual water ‘trade’ partners by category of traded agricultural commodity

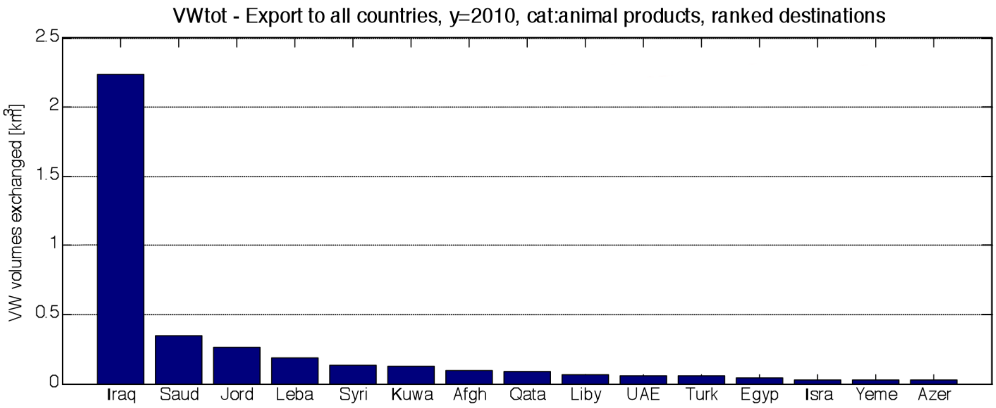
C1-C4. Virtual water ‘export’ destinations: volumes (2010)

Crops



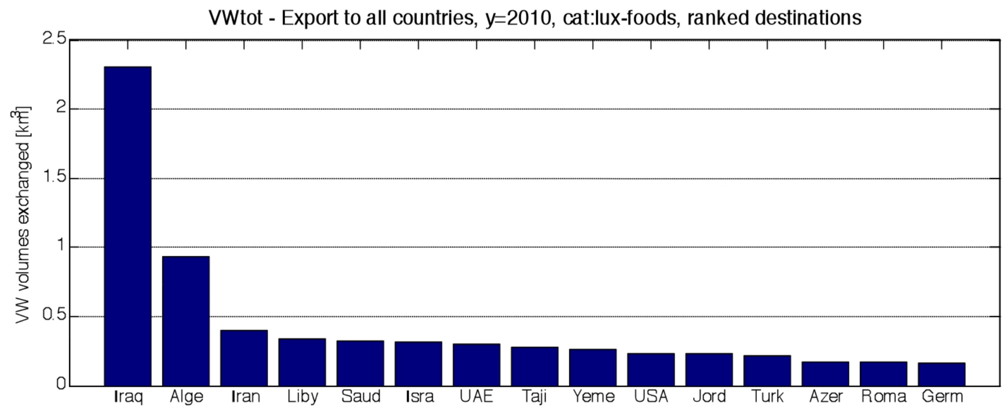
[1]	'Iraq'	[6]	'Russia'	[11]	'France'
[2]	'Italy'	[7]	'Indonesia'	[12]	'Germany'
[3]	'UAE'	[8]	'Syria'	[13]	'Egypt'
[4]	'USA'	[9]	'Morocco'	[14]	'Spain'
[5]	'Saudi Arabia'	[10]	'Hong Kong'	[15]	'Jordan'

Animal products



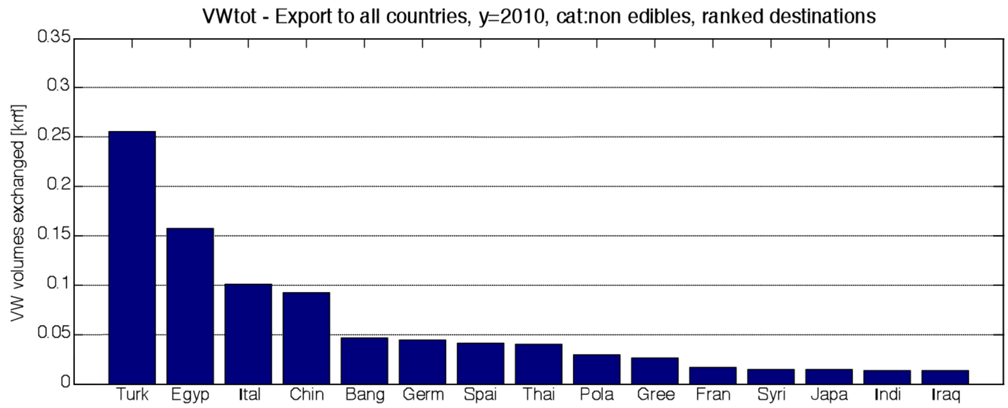
[1]	'Iraq'	[6]	'Kuwait'	[11]	'Turkmenistan'
[2]	'Saudi Arabia'	[7]	'Afghanistan'	[12]	'Egypt'
[3]	'Jordan'	[8]	'Qatar'	[13]	'Israel'
[4]	'Lebanon'	[9]	'Libya'	[14]	'Yemen'
[5]	'Syria'	[10]	'UAE'	[15]	'Azerbaijan'

Lux-foods



[1]	'Iraq'	[6]	'Israel'	[11]	'Jordan'
[2]	'Algeria'	[7]	'UAE'	[12]	'Turkmenistan'
[3]	'Iran'	[8]	'Tajikistan'	[13]	'Azerbaijan'
[4]	'Libya'	[9]	'Yemen'	[14]	'Romania'
[5]	'Saudi Arabia'	[10]	'USA'	[15]	'Germany'

Non-edible agricultural products



[1]	'Turkey'	[6]	'Germany'	[11]	'France'
[2]	'Egypt'	[7]	'Spain'	[12]	'Syria'
[3]	'Italy'	[8]	'Thailand'	[13]	'Japan'
[4]	'China'	[9]	'Poland'	[14]	'India'
[5]	'Bangladesh'	[10]	'Greece'	[15]	'Iraq'

Source: Elaboration based on Tamea et al. 2013 and Carr et al. 2013